Approaching 3D Digital Heritage Data from a Multi-technology, Lifecycle Perspective

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Abstract
3D digital data has become an essential resource for many heritage research and interpretation projects. It is critical to consider the full range of steps in the data lifecycle to insure that the most effective approaches are used and to increase the potential for reuse. We suggest that the lifecycle includes (a) acquisition/creation, (b) fusion and semantic representation, (c) storage, (d) query/retrieval and fusion, (e) analysis and presentation and (f) archive. Much of the acquired data (e.g. laser scans, images, etc.) is unorganized and initially without semantic content. The extraction of semantic elements from such unorganized data is a particular challenge. The lifecycle should be seen as recursive as outputs from one step may cycle back to serve as inputs to others. Thus semantic elements extracted in query/retrieval step may serve as key inputs in the extraction of semantic content from other unorganized data.

Keywords: lifecycle, 3D, scanning, CityGML, archive, semantic content.

1. Introduction

In the past few years 3D digital data for heritage materials, particularly the built environment but also objects, has grown in importance and use. Many technologies are involved in the capture or creation of such data (e.g. laser scanning, LiDAR, photogrammetry, CAD, etc.). At the presentation end of the process many other techniques are used in the display and analysis of 3D heritage information (e.g. augmented reality, virtual reality, animation, rendered stills, etc.). For the great majority of 3D heritage efforts the great complexity (and frequently the cost) of the hardware and software involved have necessarily focused efforts on moving directly from the acquisition/creation efforts to development and presentation of a specific set of work products. In this paper we, instead, look at digital 3D heritage data from a multi-technology, multi-presentation objective. Our perspective is informed by a lifecycle view of the data and its re-use, and the recognition that preservation, reuse and integration of multiple data streams is needed to effectively exploit these extremely valuable but often complex and costly data (BORGMAN 2007a, BORGMAN 2007b).

2. An outline of heritage 3D data life cycle stages

Our approach recognizes six (6) key phases in the 3D heritage data lifecycle:

(a) acquisition/creation

(b) fusion and semantic representation

(c) storage

(d) retrieval and fusion

(e) analysis and presentation and

(f) archive.

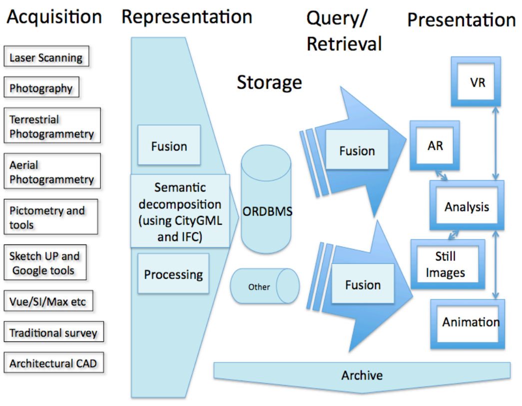

Figure 1. *The 3D Heritage lifecycle*

2.1 The value of a lifecycle approach

We argue that recognition of this lifecycle structure and adoption (when appropriate) can increase the value and reuse of these high value data but recognize that this approach can add additional costs. In the left column of

Figure 1 are listed a number of 3D acquisition (and creation) technologies. The technologies that are primarily focused on acquisition include laser scanning (e.g. aerial LiDAR, terrestrial scanning and short range scanning), photography (non-metric, commonly historic photography), terrestrial photogrammetry (especially approaches using newer soft-bench terrestrial photogrammetric software), aerial photogrammetry (both satellite and aircraft), and oblique photography and tools to acquire 3D representations such as that offered by Pictometry ™. The next technology (SketchUp™) bridges the boundary between acquisition and creation as it provides tools for both. Direct creation of 3D content is provided by technologies such as animation software (e.g. Vue™, SoftImage™ Studio 3ds MAX™, Cinema 4D™, Blender and others). Architectural CAD products such as AutoCAD™ especially it's Revit™ and Bentley's offerings are also commonly used to create 3D content – often in the absence of other data sources. Finally traditional survey methods (total stations, EDM, etc.) are frequently sources of data for CAD and other creation strategies but are not themselves commonly considered 3D data acquisition technologies.

The next section, representation, includes the processing steps that convert raw data feeds into some intermediate data format as well as (sometimes) the activities that convert or assign semantic meaning to these data. In this lifecycle approach we will emphasize, where appropriate, the importance of semantic decomposition of data inputs using structures adapted from CityGML (DOLLNER 2006, KOLBE 2005 and OGC 2009) and Industry Foundation Classes (FARAJ 2000 and IAI TECH 2009) – particularly as modified for heritage purposes (e.g. LORENZINI 2009). In the acquisition/creation column we have ordered the methods from top to bottom in the general degree to which the data are initially semantically structured. In laser scanned data the data product (point clouds) has no semantic meaning. At the other end, CAD, semantic meaning can be embedded in the creation of data – or not.

In the storage segment of the life cycle we emphasize the use of object-relational databases wherever possible, though it is recognized that other storage formats may be needed.

Query/retrieval involves the obvious retrieval from storage of needed elements but also involves the processes of fusion of two or more data formats (for example CAD elements fused with textures derived from orthophotography) as well as the complex process of retrieval based not only on semantic properties but topological and geographic properties, including view frustums as well as levels of detail (LOD).

The selected elements are then provided to the presentation stage that includes not only display but also analytical elements as well.

Orthogonal in concept yet still essential to the data flows described above is the archive stage. This stage involves those processes and operations necessary to move both "raw" data and data with semantic content and analytical outputs to a sustainable archive setting. There are a number of existing strategies for the archiving of many but not all elements of the lifecycle from the acquisition to presentation (e.g. Archaeology Data Service (2009) and SAVE ("Serving and Archiving Virtual Environments" 2009)). A new but ongoing effort, supported by the Andrew W. Mellon Foundation's Scholarly Communications Program, is working to expand these to more components and will also be discussed below.

2.2 Previous approaches to lifecycle in heritage 3D.

A number of previous authors have provided insights into the heritage 3D lifecycle. For example, Niccolucci and Herman (NICCOLUCCI 2004) provided the following view.

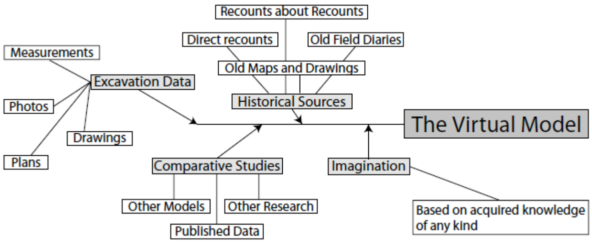

Figure 2. *Common 3D workflow (NICCOLUCCI 2004)*

A more recent proposal is that by Remondino and associates (REMONDINO 2009)

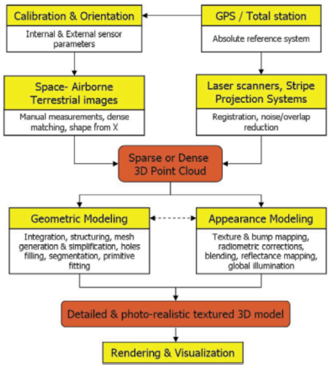

Figure 3. 3D *Scanning workflow (REMONDINO 2009)*

Another useful example is that of Levy and Dawson (LEVY 2006) and there are others published in previous CAA Proceedings and various proceedings from CIPA conferences, various ISPRS Working Groups (esp. WG III/2 and WG V/3) and others. These examples, and the one we initially present, all provide a more or less linear, directional view of the process – typically ending in a visualization work product. As we will discuss in more detail later, a more developed view sees the process, or at least aspects of the process, as recursive. In this sense, some data elements that were the outputs of later steps in the lifecycle return to serve as one of inputs into earlier ones.

2.3 Why consider a comprehensive lifecycle?

There are a number of important reasons to consider the full lifecycle of 3D data. The first is that these data are costly to develop and wherever possible should be available for reuse. Planning for future reuse of data may require modification or elaboration of the initial acquisition process and such a need might not become evident without consideration of the full lifecycle. As a simple example scanner data initially acquired without geodetic control and thus having only relative location specificity will be much more difficult to integrate with data acquired in the future. In the worst case example, spatial data collected and stored without metadata of any kind is basically useless to future researchers. Reuse lowers the total expense since already acquired data need not be repeated. In a fundamental sense reuse is a foundation of scholarship, as we should see the results of some earlier effort serving as the foundation to a future one. In a practical example an architectural element, an object or even an entire structure (or group of structures) created by one researcher should be capable of being included in a representation made by another. Alternatively the specific details of the digital representations of two elements or objects that were acquired and processed by different research groups at different times can be compared and contrasted. This position has been made most effectively by Koller and associates (KOLLER 2009) and is the conceptual basis for the SAVE initiative at the University of Virginia (SAVE 2009).

Related to these purposes but somewhat separate is the question of archive and discovery of these digital objects and the steps and information needed to accomplish this. The critical role of effective archive of digital objects has become more evident. The efforts of many bodies in the UK and Europe have been ongoing and by way for example an entire session of the 2010 CAA Conference was dedicated to this theme. In the US less emphasis has been placed on this area but the situation is changing. Recently the US National Science Foundation has announced a requirement (NSF 2010) that ALL applications for support include a robust digital data management plan. Any effective archival process will require that appropriate metadata be acquired and this will often mean that specific steps are necessary early on in the lifecycle. In the specific area of 3D heritage data there has been good initial guidance as to the archival requirements for some forms of 3D data in the Archaeology Data Services' Guides to Good Practice. Current ADS guides cover archival considerations for some aspects of 3D data such as virtual reality (e.g. FERNIE 2002). Another valuable source specifically for photogrammetry and laser scanning has been the English Heritage's Metric Survey document (BRYAN 2009). Currently there is an initiative underway that will provide a second generation guides suite – and ones that will more completely cover many of the heritage 3D formats (KIERON 2009).

Another reason to consider the full lifecycle is the recursive nature of the process. For example the CAD output from the semantic processing of a point cloud can be augmented and revised then used in future point cloud extractions where data from adjacent structures are acquired. More significantly we need to not view any specific visualization as the "final" product of our 3D efforts. Given the complexity and time involved it is understandable that the creation of a high quality product might be seen as the end objective. We would argue, however, that (a) many of the various "intermediate" work products need to themselves be seen as final products and archived, (b) that any single visualization is only one alternative from a range of possibilities and (c) that any single visualization work product informs and influences future data acquisition and visualization processes, and can most likely be improved upon by future software improvements.

As we consider the benefits from a lifecycle approach we need to be cognizant that this workflow clearly adds complexity, time and (almost certainly) cost to any single project. It is only when the larger objectives and when multiple efforts over time are involved that the benefits outweigh the costs.

3. Lifecycle components considered

We have described a number of different acquisition and creation options. It is valuable to compare and contrast the way in which they provide semantic content and the role of semantic content in our process as well as the different ways in which these inputs serve the entire lifecycle.

3.1 Laser scanning

An increasingly valuable data source for 3D heritage purposes is laser scanning, both long-range (e.g. structures) and close-range (e.g. objects). We need to recognize that laser data sets may serve (at least) three quite different roles in a 3D heritage workflow. In one the point cloud (as processed) is the data product of interest and it serves as a high-quality, high-density record of a structure or object. In these cases the result is and should be archived. In the second work product the point cloud is converted to a mesh data format suitable for many visualization purposes. In meshing the points are converted to triangular facets more suitable for many graphics applications. In these cases the original data may be archived as in the first case and the mesh serves as input to other visualization processing. In the final product the point cloud serves as the framework upon which a semantic structure is built. In this case various CAD primitives representing semantic elements such as doors, walls, windows and the like are "extracted" from the point cloud. This can be done manually using software that supports CAD element drawing within and constrained by the point cloud (e.g. Cyclone™ for buildings, RapidForm ™ or Polyworks ™ for objects). Much research is also underway to provide for automated recognition and extraction of these elements. This is relatively straightforward on simple machined objects (e.g. auto parts with RapidForm and PolyWorks) but is not operational on complex architecture and specifically not on the types of relatively organic shapes and surfaces present in many heritage cases. Work is underway and some software is available for some architectural purposes (e.g. EdgeWise™) though it is clear that fully automated processing is not yet a reality except in selected cases.

3.2 Terrestrial photographic images

Photographic images also serve as inputs to multiple aspects of the 3D lifecycle. They may serve (a) as the source of textures to be applied to the 3D CAD primitives extracted from scanning, (b) inputs to multi-image photogrammetric processing using tools such as PhotoModeler ™ that then allows the extraction of semantic content, (c) as inputs to image matching software (e.g. Alice Lab's Studio Clouds™) that develops point clouds from the photography and (d) as a source of texture to be applied directly to the points or meshes. While similar, each of these has a slightly different trajectory through the lifecycle and attention needs to be paid to the points at which archival requirements exist. More significantly the future role that an image may play in the lifecycle dictates different acquisition strategies. Images for high quality textures typically will require different exposure and composition parameters than would images destined for photogrammetry. Original imagery should be considered for archive along with proper metadata (e.g. full EXIF information as well as other relevant data). Process results from the photogrammetry or cloud processing would also be candidates for archival roles as well serving as input to future steps.

3.3 Aerial photogrammetry

Many of the aspects of terrestrial photography apply to aerial but, in general, aerial photogrammetry is a more formalized process with well recognized procedures, requirements and specifications and results developed by international bodies such as ISPRS and ASPRS.

3.4 Pictometry ™

Within the last few years a new source of useful 3D data has been oblique aerial photography such as that popularized by Pictometry™ and most familiar from the Microsoft web mapping portal's "birds eye view" imagery. With appropriate software it is possible to quickly extract both semantic content (e.g. CAD elements) and image textures from this type of data.

3.5 SketchUp ™

The SketchUp 3D drawing software provides a very powerful and inexpensive solution for the creation of original 3D data. As such it is only one of many CAD packages that provide similar capabilities. We have noted a number earlier. SketchUp (and other CAD software) also play a central role in other aspects of the lifecycle as they are the often the tools though which annotation of the semantic content can be accomplished. Thus it is possible to extract a specific element (e.g. "door", "window") from the unorganized data (imagery scanning, etc.) as a 3-dimensional textured wire frame. It requires (currently) manual annotation of the element in solutions such as SketchUp to assign full semantic content. Thus SketchUp and other CAD software sit in two locations in the lifecycle – as creation tools and as processing/annotation tools. We will reconsider this later part in more detail below.

3.6 VUE ™, C4D™, 3ds Max™, Blender and other animation tools

Traditionally another 3D data creation suite consists of a broad range of what are called animation tools - with examples such as the commercial software VUE, Cinema 4D, Studio 3ds Max, Soft Image XSI and open source solutions such as Blender, as well as many others in both categories. We continue to include these tools in the heritage data creation category but are increasingly becoming aware that data created in these tools is frequently difficult to reuse or repurpose. It is not impossible but can be challenging. As a result we believe that their role, while very substantial, will fall further along in the lifecycle. The actual creation of 3D data will commonly be accomplished in other software and the tools in this section will serve as the vehicles to increase the visual detail, provide for complex animation products and otherwise "polish" the basic 3D components created elsewhere. In some cases these products can export X3D, a 3D data format that can be used by many other software (c.f. NICCOLUCCI 2006).

3.7 Traditional survey

As we focus on the new instruments and next generation software we need to keep in mind the role of traditional survey methods. Though now updated with survey grade GPS, land survey procedures provide the global location to which all heritage data must conform. Too much 3D (and other) heritage data exists in only relative coordinate systems, making its long term integration much more difficult if not impossible.

3.8 Architectural CAD

The final part of the acquisition/creation phase we have labelled as “Architectural CAD. “ We are using this as shorthand to label the massive amounts of existing as-built and other similar CAD documentation on the existing built environment. Many heritage 3D activities may need to “place” their results within the current community and such sources are critical. We should note, however, that existing CAD documentation for most structures requires massive work to make it useful for heritage (or any) 3D analysis or representation.

4. Fusion and semantic extraction

Once various input processes are completed that next major component of the lifecycle we have termed fusion and semantic extraction. By fusion we refer to the integration of many of the input data streams as has been noted previously. In this stage, for example, data from scanning is merged with photo textures, CAD elements are extracted from imagery or scanning, and phototextures applied, and so on.

4.1 Semantic structures

A fundamental component of the entire heritage lifecycle structure proposed here is the necessity for the semantic representation of the 3d information. Reuse, discovery, and interoperability are all predicated on the ability to provide a rigorous semantic structure. Fortunately much work has already been done in this arena and the use of the OGC specification for CityGML serves as an ideal framework for heritage 3D data. CityGML has been under development, largely but not exclusively, in Europe with much of the key work by Kolbe and his associates (KOLBE 2005, 2009, GROGER 2008, multiple papers in SESTER 2009). Others have already noted the value of CityGML to the heritage community (LORENZINI 2009) and the designers explicitly called out heritage applications as a motivation in its creation (e.g. GROGER 2009:102).

Because it is based on the general XML system and more properly on the GML (Geographic Mark Language) CityGML also serves as an interoperable data specification and an archival one. It provides for multiple levels of detail (LODs) and thus can address a very broad range of structures and features. It is not adequate, however, for the assignment of semantic content to the typical objects found in heritage applications, pottery, stone tools, sculpture etc. At this point in time no specific candidate for this has emerged but is seems likely that X3D or a variation on that may serve as the basis for carrying object based semantic content. This is an important research direction.

4.2 Assigning semantic content

Generating semantic content consistent with CityGML encoding procedures is relatively straightforward but requires specific software tools – lists of current tools can be found on the CityGML web-site www.citygml.org. A common product is the CityGML plug-in for SketchUP. This allows the creation and editing/annotation of previously created 3D data with an output in CityGML. Another common alternative is the LandExplorer™ software from AutoDeask. LandExplorer supports the import of many 3D data formats and their restructuring and annotation into CityGML. It has capabilities for query and visualization of this format.

The extraction of semantic content becomes particularly challenging when dealing with the organic shapes that characterize much heritage data, whether these are structures or objects. At this point assignment of semantic content is largely a manual process. Research in machine vision and other automatic object recognition software is likely, in time, to provide more capable tools. One attractive direction is the application of image segmentation and aggregation to data that combines three dimensional textures. Simultaneous recognition of color and shape properties and their automatic aggregation into areas of homogeneity and heterogeneity appear to be useful future research directions. A commercial example of this approach is the eCognition™ system.

5. Storage and query

The storage of the various 3D data formats presents considerable challenges. Data types include point clouds photographs, CityGML, and others. At this point no single storage structure appears to be adequate for all these formats but the current release of the commercial Object-Relational database Oracle 11gR2 provides native support for many. For data formats not supported directly by the database it is possible to store blob versions and/or continue to use traditional file based systems but these do create management challenges. It is possible to query the database using a range of options that include the obvious attribute based query but which also include spatial, topological and view-frustum options. It would be desirable to have open source alternatives but, as yet, none of the current open source ORDBMS software provides these capabilities.

Figure 4 summarizes much of the discussion presented so far. It takes the conceptual lifecycle ideas presented in Figure 3 and illustrates the specific operational steps that are needed. More than the earlier figure it shows the recursive nature of many aspects. It does not, however, graphically show that the outputs of various visualizations serve as vehicles to inform future data acquisitions and further visualization efforts.

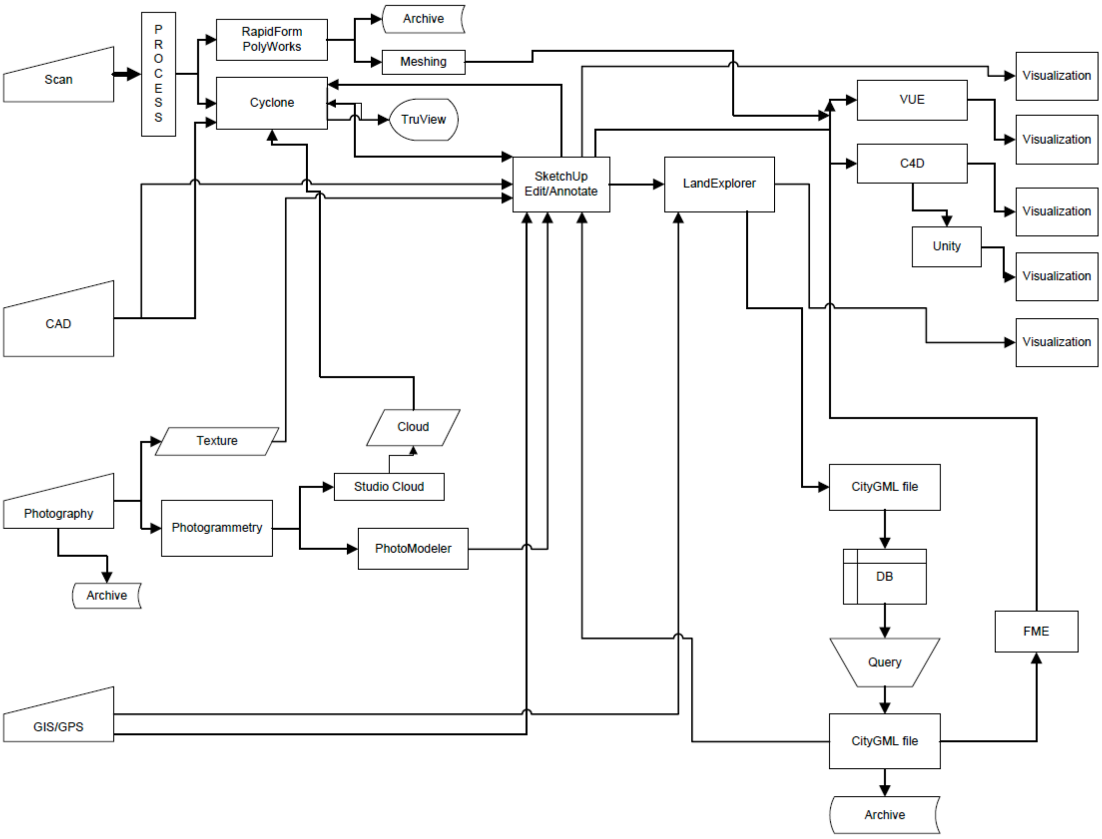

Figure 4. *3D lifecycle workflow structure*

6. Presentation

Presentation covers the wide range of ways in which the 3D heritage information can be structured to be consumer. Typically this has been via some form of still image rendering or via animation and such activities will continue to be important. As data types expand and technology advances, however, there are many other categories that fall within this rubric. One of the most exciting is digital analysis of the 3D objects. In this situation the objects are not simply viewed but the user can interact with the object digitally performing various measurements. An example from our recent work is the Hampson Virtual Museum (accessible at hampson.cast.uark.edu PAYNE 2009). In this web application the user can perform basic metric analyses on a 3D PDF version of a heritage object (pottery vessels, stone and shell tools etc.) or download a high-resolution OBJ version as well as free software from the site to conduct detailed studies and make observations.

A growing area of presentation is various immersive technologies such as dynamic stereo walls and other settings where the user can control aspects of their involvement with the data - such as interactively moving through a building. These approaches are very appealing but have a deeper intellectual component as they provide at least some opportunity to encounter the past in a phenomenological or sensuous manner, expanding the ways in which past architecture and landscape can be investigated. Coupling this experiential element with analytical tools such as spatially contextualized database queries appears to have the potential to open exciting new intellectual paths that fuse both scientific and artistic states. An excellent example is Fredrick and associates (COLE 2010) work on Digital Pompeii accessible at pompeii.uark.edu.

Another key aspect of the presentation stage of the lifecycle is the recognition of the role of query and reuse of digital objects and data. Much of the value in the presentations stage is the fusion of multiple data streams and the integration in new work product of 3D objects created in earlier ones.

7. Archive

We have previously noted the essential role of archival considerations throughout the lifecycle. We note here that particular significance of development and exposure of well recognized metadata in order that search and discovery tools can locate these digital objects and so that future investigators have adequate data to make judgments about the data.

7.1 Metadata considerations

Guidance on many of the 3D heritage metadata elements and content will be available in late 2010 as part of the previously discussed Guides to Good Practice (G2GP) updates. Local distributors and hosts of 3D heritage data for wider consumption should recognize, however, that there are a number of other steps that should be taken to insure the widest discovery and reuse of data. The G2GP (current and forthcoming) provide guidance on how the widely used Dublin Core metadata specifications should be used (DCMI 2010). In order to insure that the digital objects are properly cited, it is essential to provide for a permanent uniform resource locator. This is essentially an unchanging URL that always will provide direct access to the same digital object. There are a number of technical strategies that are available for such an approach. One is the Persistent Uniform Resource Locator (PURL – information at purl.oclc.org), another is the digital object identifier (DOI) system with information at www.doi.org. There are other possibilities but the essential goal is to provide an unchanging link to each version and type of the digital representation of an object and each severable component when there are many. For example a 3D recreation of a Roman town might have many structures and various types of city furniture. Ideally each would be a discrete digital object with its own locator.

The presence of an unchanging URL is one aspect of effective reuse and scholarly dialogue for digital objects but additional metadata is needed to allow rapid and consistent citation. Scholarly citation of digital objects generally and 3D heritage objects specifically, is a key step in the rationalization and improvement of the role of these materials in research and scholarship. An effective vehicle for this is to apply the ContextObject in Spans (COinS – information at ocoins.info) structure to each object. This system which is widely used allows a set of Dublin Core elements to be embedded in the digital object description. When the object is accessed or used compatible bibliographic software (e.g. Zotero, EndNote, etc.) can automatically formulate a proper citation to the object including author, data location, digital rights, etc. making both use and citation much easier and, therefore more likely.

8. Conclusions

We have presented the case that consideration of a multi-technology 3D digital lifecycle is an effective strategy for heritage applications and projects. Such an approach has considerable value in increasing the potential for reuse, effective archive and involvement in scholarly discourse in the future.

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