Additive Archaeology:

Towards a *virtual archaeology* reprinted?

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So, where to begin?

Let us start, this time, with an archaeological version of the Ouroboros.

Field archaeology, specifically excavations, to some people might seem, not without reason, to represent some kind of externalisation of an anarchic, destructive, drive in the archaeological psyche. The excavator in creating one kind of archaeological record effectively devours, and efficiently effaces, the original, 'proper', archaeological traces or residues from which the record is censored, and an archive created. The archive then becomes, according to Jacques Derrida, the place where things begin, the new starting point the nexus of a new reality, where impressions, collected while 'digging', become reality, embedded in the self-replicating topology of the archive. Many other potential realities become lost in a fog of institutionally induced amnesia, where all the selections and decisions that brought the excavator to this point along the path are largely forgotten, with other voices being muted, and nuanced narratives deflected into the margins

Virtual Archaeology was conceived during a period of significant changes to archaeological practice and tools

‘ Preservation by record’

- Rescue/Salvage archaeology lobby resulted in 1990 Planning Policy Guidance note (PPG) 16 introduced UK government
- PPG 16 made developers in England and Wales responsible for determining the archaeological impact of development and provide mitigation or protection, usually by paying for evaluation and excavation

Archaeology as a craft discipline

- A process and a product involving a continuous dialogue between archaeologists and the technology/tools they wield, both unconsciously influenced by professional norms

New tools implying new and different archaeological practice

- Produce entirely new sort of data and information
- Cause implicit knowledge to surface and become explicit and open to re-evaluation

Throughout the ‘70s and ‘80s, the ‘rescue’ or ‘salvage’ archaeology lobbies in UK and north America had successfully built a *polluter pays* platform by positioning archaeological remains as priceless, irreplaceable resources under threat. Public outcry about the treatment of several high profile archaeological remains had helped precipitate PPG 16 in the UK. Henceforth, developers in England and Wales were held responsible for determining the archaeological impact of development and to provide mitigation, or protection. If the remains could not be preserved *in situ,* a fastidious, empiricist archaeology, couched in the trappings of positivist science, afforded the solution known as ‘preservation by record’; in fact a set of ***pre-structured*** archives.

For me, however, archaeology, particularly fieldwork, and especially excavation, was, and is, a craft discipline. The use of tools, be they material, digital or conceptual, is the crucial factor because their influence on the direction of work done is not merely important but frequently decisive. Put simply, new tools make possible the production of entirely new sorts of data, information, interpretation, and, ultimately, archaeology (Lucas 2012, Reilly 1985).

In the 1980's archaeologists were embracing the rapidly expanding field of computer modelling and visualisation as vehicles for archaeological data exploration. Hypertext was also a very exciting emerging technology.

Unfortunately, in hindsight, the inertia of pre-existing traditions of field recording practice and epistemological assumptions had already been re-assimilated with little critical attention and now, propped-up by computerised scaffolding, were affixed with a veneer of self-evidence.

Virtual Archaeology was originally used to describe a multi-dimensional approach to the modelling of the primary physical structures and processes encountered in field archaeology

Modelling primary archaeological formations and processes to enable new ways of documenting, interpreting, annotating and narrating

Exploring the interplay between digital technologies and conventional archaeological practice

'Towards a Virtual Archaeology' CAA 1990 Revisited

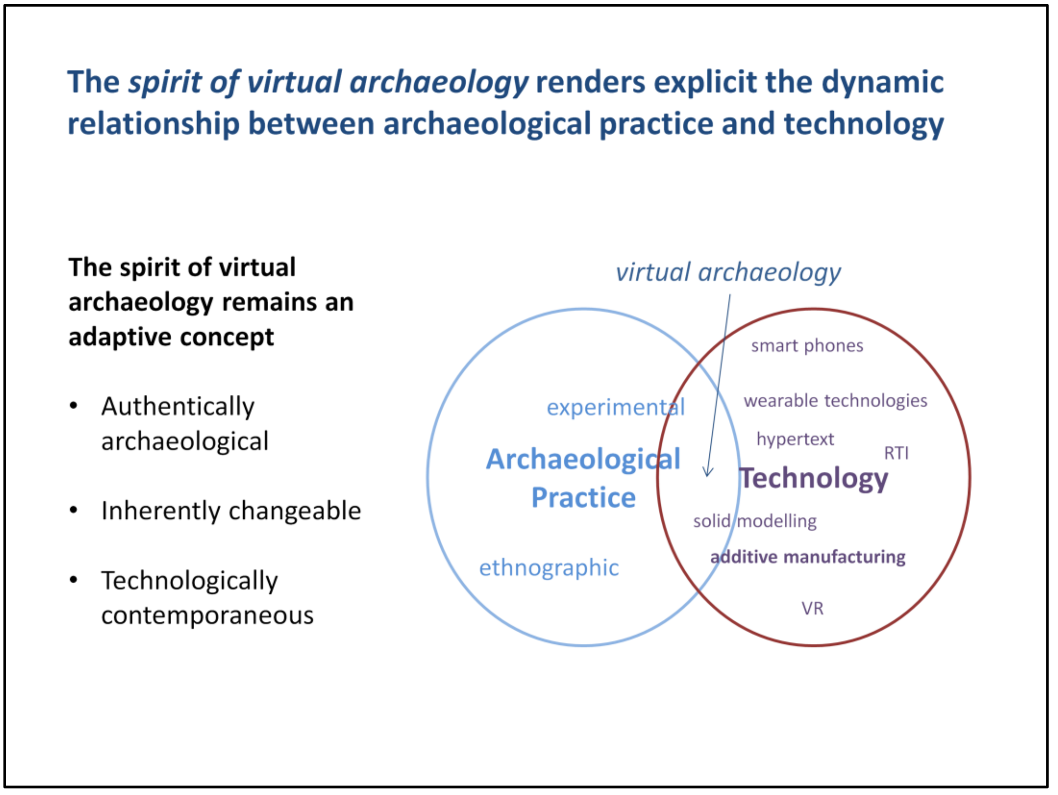
The challenge then c.1989 was to overcome this perceived methodological oversight by demonstrating that the decisions on how to explore the raw archaeology, would have a decisive influence on the reported outcomes. To me, his could only be done with something that could be taken to pieces and explored repeatedly in many different ways. At that point in time, remember, an excavation was acknowledged as an 'unrepeatable experiment'.

The impasse was broken by invoking the concept of virtuality. VA described the way in which technology could be harnessed in order to achieve new ways of documenting, interpreting and annotating primary archaeological materials and processes, and invited practitioners to explore the interplay between digital and conventional archaeological practice.

This animation - which has been abridged and annotated in the interests of saving time -- was presented at CAA in 1990 and is a very early example of using Constructive Solid of digital solids in archaeology .

The intent was to incite an epistemological rupture in conventional archaeological recording and representation of excavation data by demonstrating the arbitrariness of conventions, such as section- or plan- drawings and photographs, whilst demonstrating the possibility of developing new, radical, recording strategies, the relative advantages of which could be examined, discussed and evaluated in a non-destructive archaeological context.

In other words *Virtual Archaeology* was not only about 'what is' but 'what might come to be'?



During the period since its first articulation *virtual archaeology* has become predominantly associated with the use of 3D computer graphics within archaeological research. There can be little doubt that these activities form a part of what might be considered the 'spirit of virtual archaeology' but they do not comfortably define the limits of the original term.

VA, as first articulated, described the use of digital technologies as tools for mediating and engaging with conventional archaeological processes. This definition was broad and potentially encompassed a wide range of technologies and processes.

By the way, the term *virtual reality was* deliberately avoided whilst the importance of the non-graphical aspects of 3D-modelling were highlighted.

In short, reifying VA with a specific technology is to miss the point. The notion behind virtual archaeology was, and remains, useful for emphasising the intersection between technology and archaeological practice. For want of a better term, the *spirit of VA* describes something which is inherently changeable, and which depends on the availability of technology and its potential utility within a specific situation.

Recent technological developments have led to a proliferation of devices and software which augment, and often enhance, the human experience of the world. Consider for example, wearable technology, the ubiquity of increasingly powerful smartphones and scanners, or the development of 3D printing.

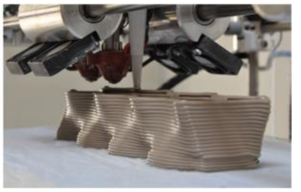
These technologies do not immerse but rather they augment. They are not synthetically haptic but authentically tactile and blended with the physical world, offering renewed sensorial prominence and perhaps more cognitive depth through material engagement.

Re-engagement with the *spirit of virtual archaeology* is possible through technologies such as Additive Manufacturing

Additive Manufacturing technologies:

Selective extrusion deposition printers

- Squirts, squeezes or sprays pastes or powders
- Nozzles, Syringes, funnels

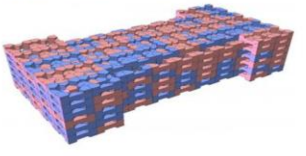


Selective binding printers

- Fuse, bind or glue the raw materials

Digital assembly

- Pre-manufactured multi-material physical voxels



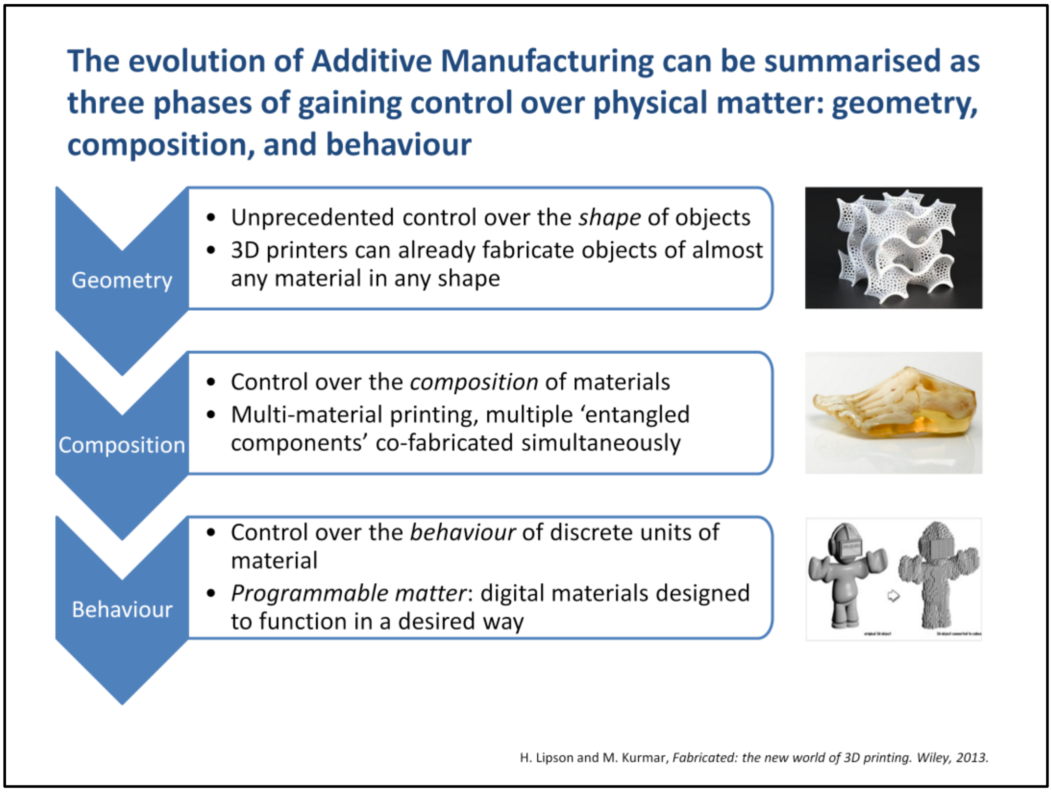
Having said that, today we'd like to touch upon ***just one*** contemporary technology, 3D Printing, or, more generally, as A.M. This potentially disruptive technology is one that enables re-engagement with some of the core concepts of VA.

Consumer 3D printing is experiencing a great deal of hype at the moment, but AM, which has been around longer than virtual archaeology, has passed over the peak of inflated expectations, through the trough of disillusionment, and is steadily advancing up the slope of enlightenment to the stable plateau of productivity, according industry analysts (Gartner 2013). At a very high level, the huge array of available AM technologies can be loosely classified into three groupings:

SELECTIVE INTRUSTION printers in essence squirt, squeeze or spray pastes or powders through nozzles, syringes and funnels of all sizes to build up objects by depositing materials in layers. E.g. ceramic bricks for large scale construction

SELECTIVE BINDING printers by contrast, fuse, bind or glue materials together, again in a layers. In this example gypsum powder is fixed and painted.

The aforementioned technologies can, in one sense, be seen as producing analogue printing or manufacturing outputs- like a battery of so many tubes of toothpaste - using digital controllers. Currently at the cutting edge is true digital assembly using pre-manufactured physical object. We can think of them as lego blocks. However, precise assembly of billions of small physical voxels made in different and multiple materials remains a huge computational and printing challenge. Of course, hybrids, deploying multiple print heads using various different fabrication methods could also be configured.



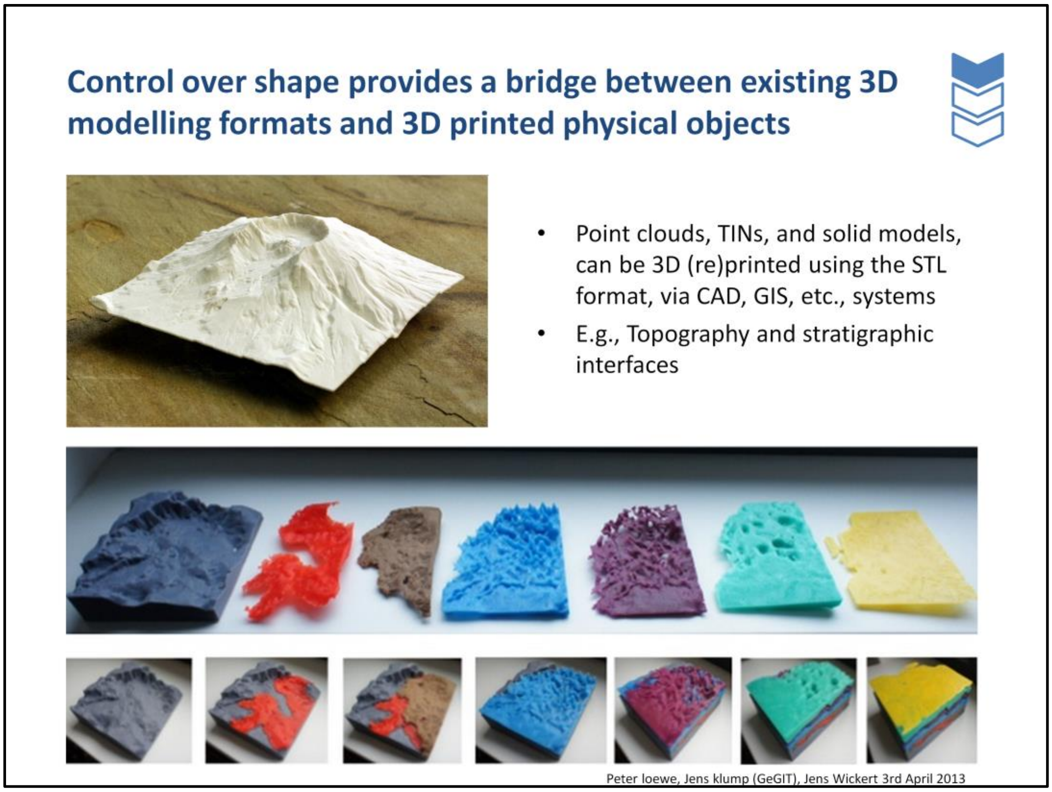
Lipson and Kurmar (2013, p 265) summarise the evolution of additive manufacturing as three episodes *of gaining control over physical matter*.

First is an unprecedented control over the *shape* of objects. 3D printers can already fabricate objects of almost any material in any shape.

Next, comes control over the *composition* of matter. We are entering a new episode where we go beyond just shaping external geometries to shaping the internal structure of materials with unprecedented fidelity, with the possibility of printing multiple materials and 'entangled components' which can be co-fabricated simultaneously.

The final stage is control over the *behaviour* of materials, where they envisage programmable digital materials- made of discrete, discontinuous units - materials which are designed to function in a desired way, eg. Spongy, transparent, in shades of grey, perhaps even embedded with nano devices.

Voxel-based printing affords the notion of different types of voxels. Imagine, if you will, a library of archaeological material-voxel types.



Control over *shape* provides a bridge between existing 3D modelling formats and the ability to repurpose them as 3D printed physical objects. Existing point clouds, Terrain and solid models, indeed any system that can output STL format files can be 3D printed.

By way of example, at the top of this slide is a 3D-printed map of the cone, crater, and summit of Mt. St. Helens in Washington, in the USA. It is available on Shapeways.com in three sizes!

The 3D printed stratigraphy you see is a stack of geology from north eastern Germany, prepared by geologists from the Centre for GeoInformation Technology at GFZ (Deutsches GeoForschungsZentrum Potsdam).
Although these are solid objects are made of a single material with the same density throughout, they demonstrate a very tangible communication.

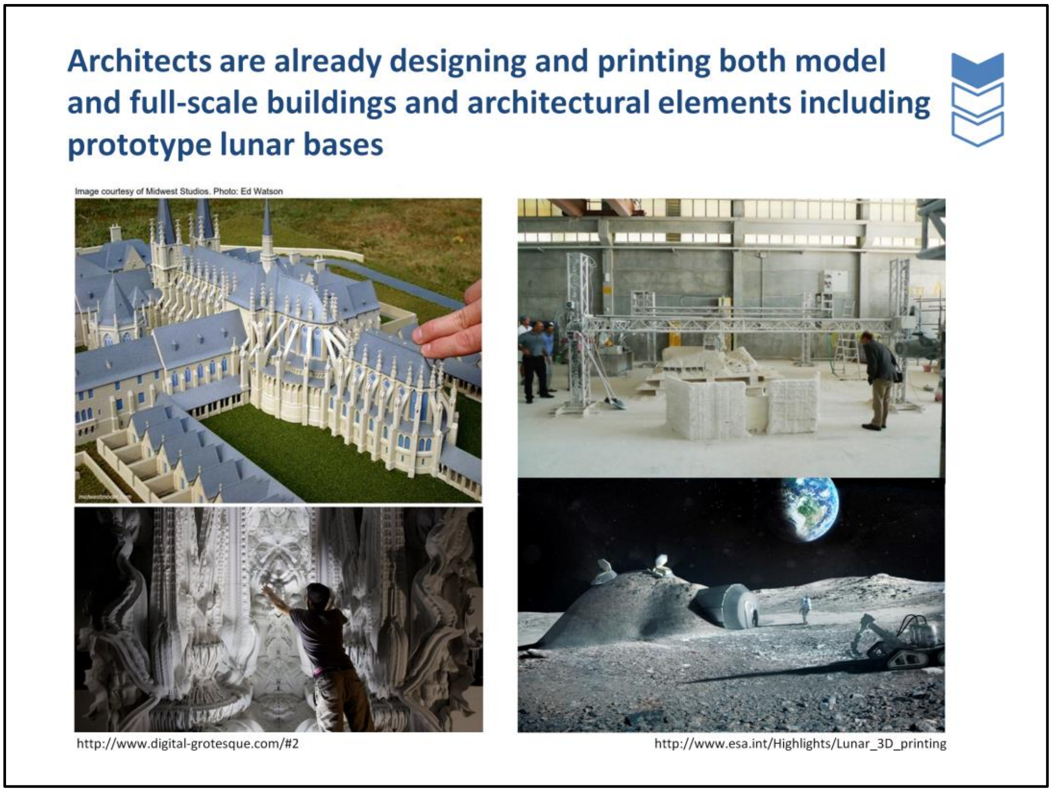
As mentioned earlier, enthusiastic makers print all kinds of materials.

Bread dough, chocolate, and other food-based materials with their pronounced olfactory characteristics introduce another cross-sensory modality into the mix. We've already demonstrated fabricators forming clay, gypsum, and plastics, but modern industrial additive manufacturing technologies span a much wider spectrum of applications, and can combine *multiple-entangle-materials* across a broader range of scales:

For example

- living-ink involving the bio-printing of living-cells in hydrogel;
- polymers for printing textiles and clothes;
- metal alloys for fabrication of innumerable parts and fixtures;
- terracotta for ceramic applications.

Here you see sand being solar sintered into glass- ,and soil, containing seeds, formed into artistic vessels.



Let’s, as it were, change the aperture of the nozzle, to demonstrate some AM examples at a much larger scale … and much further afield!

This detailed architectural model in the top left was generated by Midwest Studios from the architects’ CAD files. In keeping with the Carmelite Rule, this new foundation in Wyoming, USA, has been designed as a classic gothic monastery for the growing community of Monks of the Most Blessed Virgin Mary of Mount Carmel.

Below, Swiss architects Hansmeyer and Dillenburger created this 3D printed ultra-modern, gothic-like interior. Dubbed the “Digital Grotesque”, this room was assembled from 64 massive separate printed sandstone-like parts, and contains 260 million surfaces printed at a resolution of a tenth of a millimetre. The 11-ton room took a month to print but only a day to assemble (Voxeljet printer).

On the RHS, The European Space Agency (ESA) and architects Foster+Partners are exploring the feasibility of building future moon bases using Fabricators exploiting local materials, that is the regolith or lunar soil. Of course, here – and this is central - they are using simulants(virtual properties).

3D printing is revolutionising the *finds tray*, conservation and curatorship, as virtual assemblages of iconic artefacts are created and available globally in transcultural space

Shifting the meaning of scale somewhat, let's briefly consider the revolution 3D printing is causing to the finds record and other archaeological assemblages.

The Smithsonian museum, for example, has embarked on the ambitious X3D project, which aims to digitalise all 137 million iconic items in its collection, and make them available for 3D printing anywhere in the world.

In so doing they are also making them available for transcultural discourses within ethnographic archaeologies, in the sense of Castañeda and Mathews (2008)

Replicating virtual cuneiform tablets non-intrusively using CT and 3D printing affords tangible interaction

- CT scanning combined with 3D printing allows study of the writing with minimal handling of originals
- Cuneiforms replicated in different materials at different scales
- Interior features of the cuneiform facsimiles can be ‘opened’ so that sealed writing can also be studied without damaging the original artefacts
- The spirit of virtual archaeology moving beyond the purely visual to include the tangible

Project Members: N. Gangjee, H. Lipson, D.I. Owen. Cornell University

Consider these artefacts: cuneiform tablets are rare. Rarer still are specialists who can decipher them.

Export from their modern countries of origin, or discovery, is, unsurprisingly, restricted. However, specialists from around the world want to examine every minute detail of the tiny fine characters, and photographs and drawings are generally regarded as inadequate transcription.

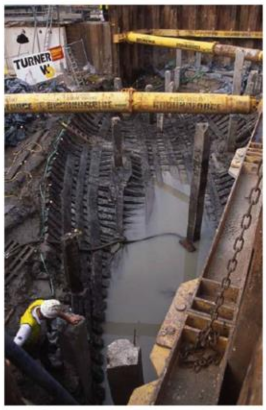
Researchers in Cornell University have developed an approach exploiting CT scanning combined with 3D printing to allow detailed visual and tactile examination of the tablets with minimal handling of the originals.

The cuneiforms are printed or re-printed in different materials at different scales. The facsimiles can be broken open to reveal sealed writing within the interiors. These hidden texts are thereby made available for study without damaging the original artefacts.

Such virtual artefacts, are easy to export electronically and download anywhere, rematerialised in any multivalent, transcultural space.

Reverse-engineering the construction of the 15th century "Newport Ship"

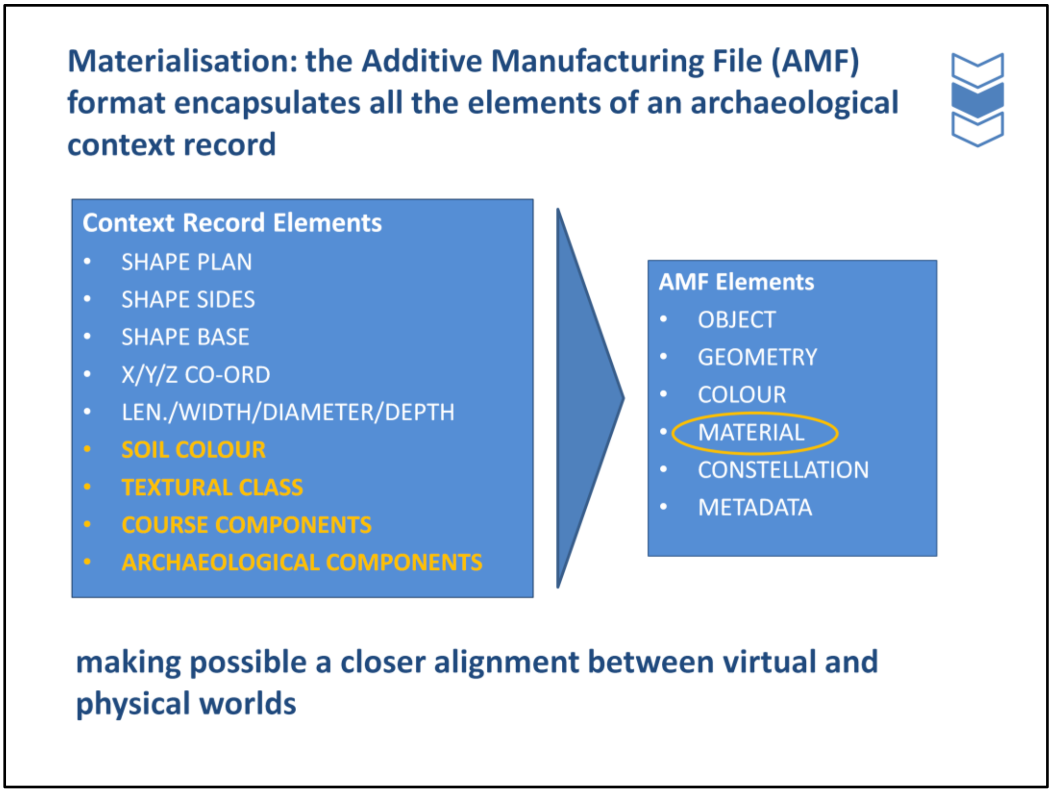
- Ship's timbers distorted and dismantled
- Conceptualising the ship's size, shape and how it was constructed is a challenge
- Original pieces too unwieldy and fragile to handle
- Printed 1:10 scale parts allow for repeated handling and enable experiments with different simulated material characteristics



Source: Photograph courtesy of Newport Museum and Heritage Service

In this example, AM is used to reverse engineer the construction of a medieval ship.

Briefly, AM technologies not only produced an accurate geometric model to assist the reconstruction of a 15th century ship found in the River Usk in S. Wales, but also demonstrated how material-characteristics can potentially be controlled to contribute to a better understanding of the original artefact's construction than is possible within traditional approaches.



Let us now become more speculative, more aspirational, and explore a few facets of AM pertaining to materialisations of virtual archaeologies that might come to be.

As AM evolved, from producing primarily single-material, homogenous shapes to producing multi-material geometries in full colour with ***functionally graded materials and microstructures***, it created the need for a standard interchange file format that could support these powerful new features. The response was the Additive Manufacturing File Format (AMF), an open standard for describing objects for AM processes such as 3D printing.

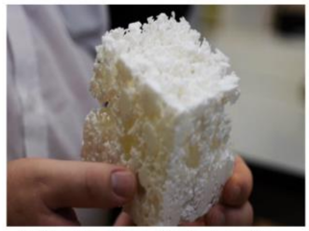
What is striking about the AMF format is that it encapsulates the typical recording sheet used on a modern archaeological excavation, but does so in much finer *spatio-compositional* detail. If we did recast our recording method to generate contexts described in an AMF-like format, we suggest that archaeology would be a step closer to aligning the virtual and physical worlds, and a step closer towards the possibility of rematerialising archaeological entities '*found*' in the field.

So what is to stop us from recording our excavations in such a way as they can be refabricated?

Our current methods are clearly deficient here, but we're not suggesting 3Dprinting all our excavations. We submit that if we recorded in such a way that we could (rematerialise/refabricate our excavations), then we would have improved substantively our practice. Some will argue that current procedures are adequate for current needs. We counter, that in an uniquely destructive discipline, are we not ethically obliged to strive for superior recording practices?

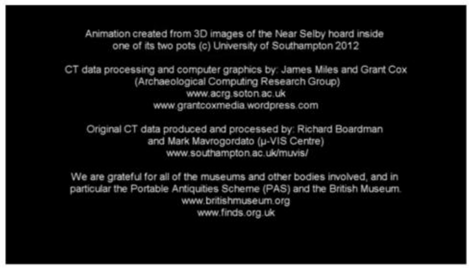
Near *in situ* virtual (re)excavation of some contexts, soils and archaeological components revealing their intricate and detailed structure and form non-intrusively

Computer Tomography (CT) with 3D printing provide the ability to examine the structure of soil ‘close up’ and, for example, set-up multiple experimental investigations



W. Otten & R. Falconer, Abertay University

CT allows a detailed, non-intrusive investigation of a coin hoard in situ within a pot, with individual coins being isolated virtually from the fill and 3D printed



R. Boardman, G. Cox , M. Mavrogordato & J. Miles, University of Southampton
https://vimeo.com/45452797

Let us offer you, finally, a glimpse of ***Additive Archaeology*** – the essence of a virtual archaeology materialised through additive manufacturing: 3D printed soils and virtual excavations involving both scientific visualisations and 3D printing.

Combining CT and 3D printing, soil scientist have the ability to explore something so intricate and detailed as the structure of soil, close up, and set up multiple experimental investigations in order to see, for example, how big the pore spaces are within it, how they are linked together, and how the bacteria move through.

James Miles and Grant Cox in the Archaeological Computing Research Group and colleagues in the Mu-Vis CT Centre in the University of Southampton, have been able to disaggregate and re-aggregate non-intrusively a coin hoard found in one of two pots near Selby in the north of England. The CT data, which can be resolved as down as two microns, were processed to produce both this animation and 3D prints of some of the coins.

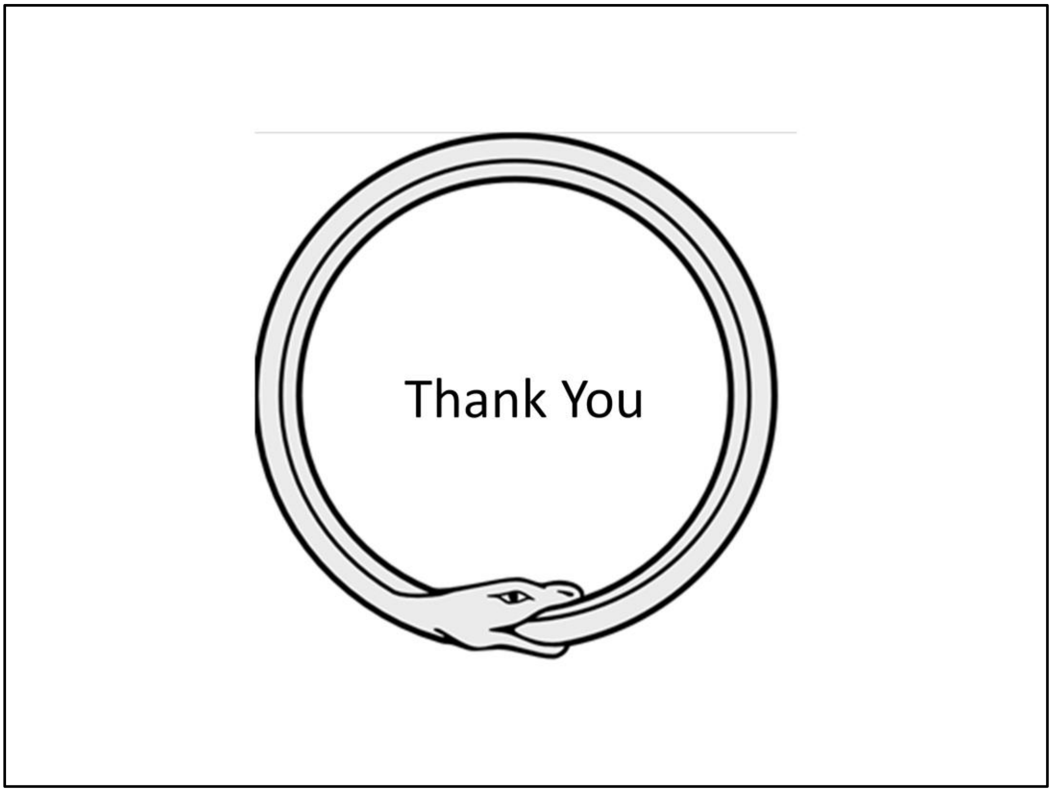
Additive Manufacturing is just one technology enabling the *spirit of virtual archaeology* to generate new 'grand challenges' to transform archaeological practice positively

- 3D printing of artefacts, monuments and cultural landscapes
  - Disrupt transcultural discourses and narratives
  - Disintermediate the archaeological/cultural 'authorities'
  - Nuance the debate on the ontology of archaeology

- Challenge the discipline to 3D fabricate an excavation
  - Innovate and transform traditional archaeological practices of recording
  - Explore the disaggregation and reassembly of a rematerialised archaeological intervention
  - Establish an exemplary platform for strategic innovation

In conclusion, AM is just one technology enabling the *spirit of virtual archaeology* to generate new challenges to transform archaeological practice positively. Printing artefacts, monuments and cultural landscapes is established technologically and is already starting to disrupt both transcultural, and disciplinary, discourses and narratives as direct access these *e-cultural entities* by almost anyone, almost anywhere, to materialise them in any transcultural space, effectively disintermediates the opinions, interpretations and 'authority' of archaeologists and cultural resource managers. The implications of the above abbreviated, and much truncated, thesis for archaeology are immense. Releasing the spirit of virtual archaeology into any/transcultural space will add a technological nuance to the debate on the ontology of archaeology (Hamilakis 2014)

We specifically contend that AM provides a credible challenge to traditional archaeological practices (e.g.in recording). With this in mind, we want to respond to Jeremy Huggett's (2014) call for disciplinary *grand challenges for the next generation of archaeologists,* so as to provide a catalyst for renewed innovation, strength of purpose, and direction in archaeological computing. We propose a disciplinary grand challenge to *fabricate* an excavation, ***that is an excavation - rematerialised geometrically and compositionally accurate***, whereby the curious can explore iteratively, reflexively, and comprehensively, the disaggregation and reassembly of archaeological entities encountered through archaeological intervention in such a manner as to engender a constant, multi-valent, hermeneutic cycle between analysis and synthesis. We envisage that in striving to meet this challenge, the discipline will establish elements of an exemplary platform for strategic innovation, affording the development, ***and structured introduction of*** innovative and distinctly archaeological approaches through technology(e.g., a methodology/community of interest).



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http://www.treehugger.com/gadgets/students-create-3d-grass-printer.html

http://amf.wikispaces.com/home

http://www.gizmag.com/swiss-architects-3dprint-a-room/29299/

Near Selby hoard: http://vimeo.com/45452797 **Animation showing Computed Tomography of coin hoard and visualisation of the hoard**
Slide #7
Mount St Helens, washington

http://www.slideshare.net/loewe/scientific-3d-printing-gfz-geoinformatics-kollquium-april-2012http://www.slideshare.net/loewe/scientific-3d-printing-gfz-geoinformatics-kollquium-april-2012
Scientific 3d printing
Peter loewe, Jens klump (GeGIT), Jens Wickert 3rd April 2013
Soil
The Scotsman, Scotland on Sunday,27/1/2014
Soil: http://www.scotsman.com/news/education/3d-printed-soil-developed-by-scottish-scientists-1-3282077

exposing open, flexible, *big data*
enabling new beginnings and novel, transformative, multi-vocal iterations of virtual archaeologies

If we could record an archaeological intervention (ie., dig) such that it could be 3d printed (NB no requirement to actually do so) then with such a level of detail, is it possible, finally, to compare 'interpreted' features globally? What is a pit? A posthole? A layer? Assemblage? Entity? (virtual e-diggers, e-director: Unguided automatic statistic or machine learning mechanisms to search for implicit patterns)
Notes: GFZ project
The process starts with a physical observation, or a model, by a sensor which produces a data stream which is turned into a geo-referenced data set. This data is turned into a volume representation which is converted into command sequences for the printing device, leading to the creation of a 3d-printout. Finally, the new specimen has to be linked to its metadata to ensure its scientific meaning and context. On the technical side, the production of a tangible data-print has been realized as a pilot workflow based on the Free and Open Source Geoinformatics tools GRASS GIS and Paraview to convert scientific data volume into

stereolithography datasets (stl) for printing on a RepRap printer.