Reimagining Heritage Sculpture Practices: The Transformative Role of 3D Printing Technology

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Abstract

Sculpture has historically relied upon the artist's touch, material resistance, workshop labour disciplines, learning traditions of modelling and mould-making to chiselling, carving, polishing and finishing processes. In heritage sculpture practices such as the following case study in India, the sculptural object functions not as a mere form of visuality, but also a vessel for memory, ritual knowledge, material intelligence, community skill and embodied artistic emotion. With the rapid evolution of 3D printing, 3D scanning, digital modelling, CNC carving and laser cutting this has completely altered this domain by shifting sculpture out of a primarily hand-led and material led means to hybridised system of: file + machine + prototype/ cast + post production. The transformation is explored in this chapter through a literature- and case-study-based approach. If first it outlines that the process of sculpture was clay moulding to will then make a mould and cast into final form in bronze, fibre, plaster or other mediums. Next, it discusses the ways in which 3D printing supports rapid prototyping, resizing and copying, generation of complex forms, conservation and accessibility efforts, as well as waste minimization. It raises the limitations of the technology as well the turf by reminding us about human touch loss, machine uniformity, technical dependency, authorship debates, ethical ramifications in copy heritage and possible neglecting traditional artisans. Examples include L.N. Tallur, Barry X Ball, Karin Sander, and Morehshin Allahyari whose case studies illustrate how artists navigate the tensions between tradition and conceptualization or cultural memory and digital fabrication. The point of the chapter is that we should not think of 3D printing as mere substitutes for traditional sculptural practice. Its most important function is in hybrid practice, where digital accuracy works with human care for history and craft knowledge.

Keywords

3D printing sculpture, heritage, digital fabrication, additive manufacturing, mould making, contemporary Indian art

1.Introduction

Sculpture making today is going through an interesting period of technological change. Processes that traditionally relied on heavy human labour have been increasingly mediated by machines, digital files and computational tools. Unlike at many studios, the modelling process might not even start in clay, plaster or wax: it may begin in software. Carving is no longer just hammer, chisel, knife, rasp or file; it can also be aided by CNC milling, robotic carving, laser cutting and 3D printing. What has emerged is in the nature of a sculptural object an entity that can be first prototyped, then resized, multiplied, fragmented into parts, printed and finally assembled or cast as metal, resin, fibre or mixed-media?

This change is not only critical to contemporary art but also relevant for heritage sculpture practice. Heritage sculpture is a discipline where form, material, technique and cultural memory, ritual value and community skill are intertwined. But neither a bronze icon, nor a carved stone figure, nor even a terracotta form or hand-modelled clay image is ever merely visual. The second is the heritage of proportional systems, ways of working in the Open-ended Workshop, bodily discipline, religious or cultural significance, and a protracted cultivation of the artful personality. So, by the time digital fabrication comes into this area, it is not just altering the speed of production. It transforms the relationship of artist to object, idea to material, and tradition to technology.

Traditionally, sculptural practice starts with clay modelling. Via working directly, the artist shapes the object by hand; adding and removing material, correcting proportions, developing surface and negotiating with the work. This is then replicated in plaster, rubber, silicone, fibre or other medium.

Lastly, you can make the piece in bronze, aluminium, fiber, plaster, cement or resin. In other cases, the sculptor either carves away in stone or wood from a standing block. These are very manual and time-consuming processes. They create material waste, require workshop attention, and threaten scale. For example, if a sculpture is made at a certain dimension and the artist cannot simply press command-a to change it. The object is usually demolished, remoulded, or recast.

This is where these artists have a place because by being able to use 3D printing, their workflow changes. A sculpture idea (sculpture) digitally modelled and scanned, repaired / printed as prototype. That same record can be rescaled to 1 or smaller time and again. If, however, the artist approves a small model of what he has submitted, then they may proceed to print a larger version in parts. These segments may then be used to build and mould in metal or reassemble within a reverse engineering of the space. Here, the digital file is turned into a malleable sculptural form. It enables you to have fun with size, repetition, refine and test ideas through physical practice without going through the entire modelling and mould-making process each time.

But this convenience of technology also presents an artistic dilemma. Sculpture is not only the final form It is also touch, hesitation, correction, mistake, pressure rhythm and presence. As labour-intensive the artist is by hand as a sculptor, the record of physical effort resides in it. We may see bumps accidents or stumbles if marks on the surface but in art we often treat these occurrences as meaningful. They create a human quality in that object. Conversely, 3D printing is also capable of achieving surfaces that look excessively smooth, too clean or too robotic. As great as it may be for ideation, prototyping and production instead of an artistic view it can lack the tactility and emotional touch related to handmade work.

Thus, the argument of this chapter is chastened. 3D printing is revolutionary but it's also an oversold innovation that doesn't completely displace long-held traditions with an automatic benevolence. It brings speed, accuracy, and scalability to the table while also enabling new formal possibilities. It supports conservation and education. It allows artists to create complex pieces and experiment with ideas more quickly. But at the same time, it creates new dependencies and ethical dilemmas, in addition to aesthetic losses. The main problem is not whether the hand has been replaced by the machine, but how we can think more deeply about the relationship between this hand, this machine, this digital file, this artisan and artist and viewer.

2.Sculptural Techniques Through The Ages: Modelling, Mould-Making, Carving and Casting

The conventional process of sculpture is a stratified material action. In the case of modelling, the sculptor assembles a form from parts made from plastic medium, such as clay or wax. Compared to carving, modelling is additive, or you build the form through addition, pressure, correction and internal expansion. But clay is especially crucial because it responds immediately into the fingers. Giving the artist a chance to push, press, pinch, cut, join, smooth and re-assemble. Britannica Titles: Sculptformes Britannica explains modelling refers to a process in which sculpture is modelled or constructed from plastic media, like clay, plaster or wax, by the artist's own hands and instruments. The emotional life of traditional sculpture is located centrally in this bodily relation. (Britannica, 2026)

The next phase within a lot of sculptural practices after modelling shift into mould making. This is a standard studio process where the original clay model is coated in plaster or some alternative mould material. After the mould has properly set, it is bisected and extracted from the model. The mould is washed, assembled and filled with plaster, concrete, fibre-reinforced resin, wax or any other casting material. The latter is almost always required in at least part of a mould for sculpture in the round. Complex parts pose a challenge for release, especially in locations where an undercut is present. As highlighted by Britannica, piece moulds for large or complicated works may be put together from many sections and that piece moulding is a very exacting skilled and laborious work. It is exactly why working with traditional sculpting takes a lot of time and relies on workshop knowledge. (Britannica, 2026)

Casting it in bronze adds a different dimension of difficulty. This process of lost-wax or cire perdue, used on metal sculpture, has been widespread over various cultures. It has special heritage significance

in South Indian temple bronze traditions. According to the Smithsonian's National Museum of Asian Art, each temple bronze from South India is cast through the lost-wax process, where molten metal is poured into a manually created clay mould which is then broken open to reveal your final piece. This allows for each bronze to be as original, rather than mechanically repeated. In this way, the broken mould retains the uniqueness of an object and its making.

Bronze casting in Tamil Nādu, primarily for temples around Kumbakonam in centres such as Swamimalai is not merely technical process but tradition. The Sthapathis belong to a cast of artisans who practice techniques from the Chola period of icon-making. These include textual knowledge, ritual proportion, clay preparation, wax modelling, metal composition, furnace work, chiselling and finishing plus using a consecrated visual language. Such traditions resist collapse, thus sculpture too is a social and cultural system. Its dependent upon received training, apprenticeship, and community identity and regard for the material behaviour. (Smithsonian National Museum of Asian Art, n.d.)

Traditional sculptures like stone, wood or hard materials carving behaves in inverse way. Carving is a subtractive method. With a sculptor, they chip away at the block and cannot put whatever has been cut back. Your world is constrained by the size of the block because a block has a fixed area so the final artwork is bounded by that dimension. Enlargement necessitates fresh block and updated process. You're not just changing a scale setting, you are literally sawing off material, and the only way to reduce is by cutting. One of the biggest drawbacks with traditional practice is this fixed dimensional state, especially for artists that want to test their work at a multitude of sizes.

Thus, the conventional system encases its own value and limitation. Its value is in the touch, authenticity, craft, patience and material intelligence. The limitations of it are time, labour, cost, waste and rework. If a mould doesn't work, the artist loses material and time. If a cast is defective, the process may need to be repeated. The original is not always capable of being increased or decreased without working quite hard. Big works, complicated work: into the management of assistants, the structure of supports, bisections or at some points casting riskiness and finishing problems of details. It may be these very difficulties that went some way to making digital fabrication so appealing to contemporary sculptors.

But, on the other hand, labour should not be approached only as a problem. Labour is also meaning. Your time modelling clay, scraping plaster, carving stone or finishing bronze creates a bond between you and the object. In heritage sculpture, this link may have devotional, ethical and social implications. When a technology can promise to save labour, the scholarly question must always be saving what kind of labour, and sacrificing what kind of meaning in so doing?

3. Literature Review: Digital Fabrication, Heritage and an authenticity dilemma

Introduction The use of 3D technologies applied to heritage and sculpture has been growing in the last two decades. Notable among these is a body of scholarship on conservation and restoration. According to Acke, De Vis, Verwulgen and Verlinden, 3D technologies (data acquisition; digital modelling and manufacturing) have been applied in cultural heritage since the 1990s. In the study they identify an optimistic towards application of 3D technologies in conservation-restoration and analyse futures examples by examining sixty-five case studies of loss compensation. This literature contextualizes 3D printing within a larger digital workflow entailing scanning, modelling, reconstruction and fabrication. (Acke et al., 2021)

A second line of internal programming is based around accessibility and education. Digital reproductions can enable students, researchers, museum visitors, and even visually impaired audiences to access objects which would otherwise be physically out of reach. According to the Swedish National Heritage Board, the advantages of printed 3D models include improving people access and engagement with cultural heritage objects, enabling tactile and multi-sensory experiences without needing to handle originals or replicas, and providing options for scaling digitised objects larger or smaller. This is especially important for sensitive heritage objects that cannot be handled, moved or exhibited on a permanent basis. (Swedish National Heritage Board, n.d.)

A third strand explores our perception and experience. According to Malik, Tissen and Vermeeren (2021), it claims that 3D dissemination technologies have impacted the domains of art history, cultural

heritage; education; research, conservation and presentation in museums. They emphasize that meaningful experiences using 3D reproductions must be designed within the cultural and personal contexts of users. This is important because it moves the conversation past the hypothetical question of if an object can even be printed. It questions whether the object itself conveys meaning, value, and cultural praxis.

A fourth strand has to do with questions of ethics, ownership and repatriation. According to Oruç, 3D scanning and printing offer new openings in terms of preservation and access for cultural heritage but also transfer the question of ownership because digital scans ultimately become new objects that are subject to control. In accordance with this, recent studies on Indigenous heritage highlight collective benefit, authority to control, responsibility and ethics, Indigenous data sovereignty and co-production of knowledge as essential for 3D digitisation projects. This is particularly important for heritage sculpture, as reproduction cannot be neutral. Depending on the situation, whether it is a scan of a sacred object such as a temple image or funerary figure, or an artefact tied to certain communities etc there may be cultural restrictions at place that technical permission cannot solve alone. (Csoba DeHass et al., 2025; Oruç, 2022)

A fifth strand concerns authenticity. The reified discourse of the heritage value of an original object is based on its antiquity, physical integrity, provenance and historical existence. Replicating external geometry can be achieved via a 3D print replica, but not the material history or ritual biography and no patina, actual damage (deformation) or touch and atmosphere. The 3D models themselves may be representations, not authentic objects at all yet the Swedish National Heritage Board and others state this quite explicitly and go on to say that even a perfect outer copy of an object cannot recreate touch and tactile properties which might be vital for understanding this object. It is this limitation that sits at the heart of the artistic argument about human touch versus mechanical accuracy. (Swedish National Heritage Board, n.d.)

In the art historical sense, digital fabrication than also presents problems of authorship in sculpture. If an artist suggests the concept, a digital artist creates the 3D model, a machine prints out the prototype, a foundry makes the cast of work and assistants complete the surface where is art in this process? This question is not a new one. The casting of bronze has traditionally included founders, mould-makers, patentors and assistants. For instance, Rodin essentially operated within a methodology of modelling and casting systems that required studio work. But digital fabrication shifts the work behind this labour into visibility; it theorizes software, data, and machine translation as essential to production.

This bore hardly mention of land, labour and other aspects of its economic application, leading the literature therefore to suggest three D printing was simply not a technical tool. It is also a larger transformation in material culture. It has huge implications for conservation, museum display, education, accessibility to and rights over cultural heritage, authorship of creative works, intellectual property considerations ethics as well craft labour and aesthetic experience. When it comes to sculpture, the real question is not whether or not digital fabrication is useful. It clearly is. A harder question to answer is how do we use it without writing sculpture off as a mechanical output, and without severing the forms of heritage from communities, bodies, and matter that imbue them with meaning?

4.Methodological Approach and Scope

This chapter utilises a qualitative, literature-based and case study approach. It does not perform laboratory experiments with 3D printing materials and it doesn't showcase artist or artisan field interviews. Instead, it draws on current scholarship, museum and gallery sources, artist statements and heritage conservation literature to make sense of the transition from traditional sculptural practice to digital fabrication. It also interweaves practice-based reflection over the sculptural process: clay modelling, mould-making, casting, scale limitation, chose of materials waste and artists hand.

The scope is intentionally interdisciplinary. It brings together essays from art history, heritage studies, conservation-restoration, contemporary art and craft studies, and digital fabrication discourses. This is because one cannot solely approach the problem of how to utilize 3D printing for sculpture through technology. The machine will do the job of printing an object but the full meaning of that object is

constructed through creative authorship, cultural context, how it is displayed, its material translation and finally reception. Thus, in this chapter Indian sculptural concerns, focusing on the practice of L.N. Tallur.

The selected 11 case studies are a result of the different relation between hand and machine in each example. L.N. Tallur is a contemporary Indian practice wherein the digital modelling, handmade references to an ancient craft, prototypes and permanence of bronze can exist together. A well developed hybrid studio approach to Barry X Balls use of scan, print & fine milling in combination with hand finishing. Karin Sander is an example of a conceptual use of 3D body scanning in which mechanical reproduction is instead the very subject of the work. Morehshin Allahyari is a vital and ethical application of 3D printing with respect to destroyed heritage, digital colonialism, and cultural ownership. As a trio, these cases demonstrate that there is not one 3D printing practice there are many practices of 3D printing.

5.Sculptural Workflow: Shift From Hand to File

Of all the transformations offered by 3D printing, no shift is more important than replacing the handmade piece with the editable digital file. Traditional practice is to have a clay model — a physical sculpture with immutable dimensions. The artist can only change it, but this changing is a material act. Enlargement or reduction, which involves certain measurement, remodelling, pointing, moulding or casting. The model is a set of data and exists in that way first, before a digital practice comes into play. Through software, the same object can be scaled up and down, mirrored left and right, sliced into pieces to fill with other material or made hollow in order to displace air, thickened at the edges and texturized along its surface or smoothed across it. The sculptural becomes kinetic before it becomes material.

And with this shift comes a changed economic landscape for experimenting. In the old days, every significant change was time and material. Digital modelling still allows the artist to try out variations with far less immediate loss of material. To test composition, balance, shadow, proportion and surface, a small model can be printed. If the prototype is not successful then this file can be fixed and printed again. This doesn't mean that 3D printing is without expenses, however; misprints, support material, resin and plastics remain significant costs into your continued version runs along with the typically unnoticed expense of electrical energy perhaps labour can also be a trade-off too--although not considered here. However, it does mean that you can experiment before costly casting or final fabrication.

For a start, scale is the gloomiest thing. According to the Swedish National Heritage Board (n.d.) subtle details of small objects can be enlarged and large objects can be reduced into a size we have ability to hold in our hands. Which is a well-known limitation of traditional sculpture. Creating a 30-centimetre figure in clay does not straightaway mean an artist can make it three metres tall as well, as new technical processes have to be applied. The digital model can be resized, and printed in parts with 3D printing. This is a huge plus for public sculpture where an artist can sign off on a tabletop prototype before bringing it to large installation.

Another aspect of the new workflow is mould-making. The cast, as co-designed by engineer and jargon-whisperer Ian Merrilees, was in a traditional mould (an indispensable bridge between model and cast). The digitally assisted process can itself be a printed object that is the master pattern for mould-making. Instead, the print can be a functional prototype or it can even be printed from a castable resin for investment casting. That's because you can split the print into separate parts in larger works, and finish each part separately before assembling for casting or surface treatment. The control of an artist moves from directly in control of the model into being able to approve files, assess prototypes and be consulted on post-production.

This transformation goes beyond additive manufacturing with laser cutting and CNC milling. Laser cutting can take draw graphics made digitally and take a sheet of wood or acrylic which to cut, it could also be metal or even paper. CNC milling and robotic carving allow 3D data to be expressed as carved forms through subtractive methods. In practice, many modern sculptural studios employ hybrid workflows: the shape is digitally modelled, a small printout is made, a larger maquette is milled or

printed out, moulds of printed segments are created and hand-cast or finished works. So, the boundary between analogue and digital practice is not rigidly defined. Many artists use both.
This transformation may be illustrated by means of a comparison.

Table 1. Shift from traditional sculptural workflow to digitally assisted workflow

Aspect	**Traditional practice**	**3D printing / digital fabrication**
Initial model	Clay, wax, plaster, or direct carving; form develops through hand and material.	3D software model, 3D scan, or digitally sculpted form; file can be edited before materialization.
Scale	Fixed by the original model or block; enlargement requires new labour.	Digital file can be resized repeatedly before printing or milling.
Mould	Mold-making is central, skilled, slow, and material-intensive.	Printed prototype may reduce or modify mold-making; print can become master pattern.
Labour	High bodily labour and workshop skill; artisan knowledge remains central.	Less manual modelling in early stage; more software, machine, and post-processing labour.
Surface quality	Marks of hand, tool, correction, and accident remain visible.	Smooth, precise, and repeatable surface; may appear mechanical unless hand-finished.
Waste	Waste from molds, casting failures, carving offcuts, and repeated trials.	Potential reduction in some waste, but failed prints, supports, resin, plastic, and energy remain concerns.

6. Case Study I : L.N. Tallur and the Hybrid Object

L.N. Tallur, among the most relevant Indian contemporary sculptors to speak of new relations between continuing strife and negotiation with heritage, craft (or manual skills) and technology. Born in Karnataka, Tallur works in sculpture, installation, wall-based work and public art as well as interactive projects. His practice describes as exposing the quotidian absurdities and anxieties of contemporary life. Nature Morte My reading is that he makes heavy material but they are also playful, ironic and critical concepts. He draws from bronze, wood, terracotta, concrete, found objects, references to craft traditions, and contemporary fabrication systems to create work with a tension between sacred form and contemporary scepticism. (Nature Morte, n.d.)

This is integral for Tallur's current practice, which does not pit tradition against technology. He discusses Dhokra casting, where beeswax strings are wrapped around to be patterns of the end object in a recent interview, and notices that this is in fact an additive process as well (along with 3D printing) and performs basically the same concept of layering materials together to create objects. This observation plays a vital role in making the case for this chapter. Which says additive thinking is not unique to 2023. There are some old forms that already build aggregate, layer by layer, coil by coiling gesture by gesture. What changes in 3D printing however is that the logic of addition is mediated through data and mechanical output. (Serenade Team, 2024)

Tallur's works in contemporary production can really progress through a workflow where an idea is developed by the artist and then passed to a 3D artist who translates that idea into something digital — a model, from which they create a prototype that the artist either approves or corrects before printing creating larger versions of the piece. In some cases, much larger forms are printed in pieces that are then plated and cast. This latter process grants freedom to the artist. This is because it enables more complex formations to be created faster, allows for variations in scale and cuts down on the time needed

to restart this whole clay mould cast process whenever a formal change occurs. And it also enables the artist to envision objects that might be difficult to realise by conventional modelling means.

One helpful example is: Floccinaucinihilipilification (Prototype), 2021, which auctions record as 'print on bronze.' The term 'prototype' is also revealing. It implies a thing occupying the intermediary space of test model and finished sculpture, experiment versus finality. It also exposes the way modern sculpture progresses through digital image, prototype, print, mould, cast and final object. What Tallur has done is still artistic, but she's moved the act of artistry into conceptual framing, material choice, approval, transformation and presentation at finality. (Saffronart, 2024)

Simultaneously, however, the case of Tallur reflects the very conflict driving digital sculpture itself. If you provide just the idea and the 3D artist create the model, authorship is unravelled further and becomes multilayered. None of this is a bad thing, but it must be recognised. Assistants and artisans have always been integral in traditional studios as well. What does change is the value of their expertise. Alongside the artisan who translates clay into mould, and wax into bronze, is the digital modeller who translates concept into data. This new sculptural studio becomes a weave of artist, software, technician, printer, foundry and hand-finisher.

It is this relevance of Tallur where he is able to reveal that the digital fabrication and Indian craft consciousness can co-exist. There is no erasure of the past, but a question of how the past continues in the present in his practice. Positioning Dhokra casting alongside 3D printing, the artist proposes a fresh paradigm for viewing heritage. Tradition is neither a museum exhibit nor a nostalgia. It transforms into a live archive accessible and reinterpreted using modern tools.

7.Case Study II: Barry X Ball and the Long Arm of Technology

An international example of how digital technology can be incorporated into sculptural practice without eliminating craft is Barry X Ball. These processes are amalgamated in his studio through the use of 3D digital scanning, virtual modelling, 3D printing, computer-controlled milling as well as laborious hand carving and polishing. It is also important that this appears as a combination as opposed to an opposition, because the opposition between machine and hand is very much related to knowledge of practical skills. In the machine that Ball makes, the hand is not replaced: it is an extension of the field where work from the hand takes place. (Barry X Ball Studio, n.d.)

Ball often engages historical sculpture. Instead of rehashing past works, he reinvents them using new materials and techniques. For example, you would scan a historical figure and it captures its form digitally. This digital model can be modified, cut into stone with robotic milling, refined and fixed. Once machine production generates the basic form, it is a handwork for many hours. The end product holds both the precision of digital space and a hand finish. The look seems to be both old and new.

The point of Ball's practice is that he shouldn't have to choose between technology and tradition. He shows that digital fabrication can serve sculpture, as long as it's within some rigorous conditions of materiality. The machine is just one step of a process and his works never get fully mechanical. The ultimate surface remains out of the reach of carving, polishing, stone selection, material sensitivity and visual judgement. In that way, his practice can be seen as a model of heritage-driven sculpture digital tools can allow an artist to dialogue with precedence while retaining the logic (and beauty) of hand finishing.

Ball is useful for the current chapter because it complicates the obvious fear that 3D printing destroys necessarily any human touch. This may ensure that the art is considered final if, after printing, no further act of alteration occurs. Or if you print and mill as an intermediate step, the hand can come back in the final surface. The key takeaway from the event is that the issue here is not with the tech. The dilemma is if the technology acts as a replacement for artistic decision making, or augments it within a larger sculptural practice.

8.Case Study III: Karin Sander and the Mechanics of Portraiture

Karin Sander's 3D Body Scans provide a sort of case study. The project, which he started in 1997, scans living people using lasers and sends the data to an extruder that reconstructs them slice by slice out of plastic. MoMA lists Karin Sander 1:10, 1997, 3D-bodyscan of the livings person as an FDM work (ABS

airbrushed) on a scale of 1:10. In this instance the machine isn't even hiding behind a "traditional" finish. The mechanical constitutes the meaning of this work. (MoMA, n.d.; Karin Sander Studio, n.d.)

A (modern) view of traditional portrait sculpture: The artist studies the sitter, reads likeness, decides what to emphasize and translates character into form. The value in Sander's body scans is the writer, who is reduced to data. The body is captured and digitally reconstructed by a machine. The result is something like a 3D selfie, but one in which the artist's hand does not play much of a role in the modelling process. Such absence is not a flaw of the work it is the idea behind the work.

Sander is one of my subjects because their case offers clarity; that the lack of a human touch can be an artistic statement in itself. The work challenges the question of what portraiture is when a body is scanned as opposed to interpreted. It questions if mechanical precision can supplant artistic likeness. Finally, it poses the question of how scale, replication and embodiments shift and play unwitting tricks on us in a world where we can now be converted into 3D printable files. The emotional distance of it is, in fact, its power.

As both inspiration and caution, Sander's work is a legacy for works of heritage sculpture. It demonstrates that digital reproductions can have richness of concept. But it also demonstrates the ease by which technical representation can displace a hand-contrived reading of warmth. This poses a painful question for heritage objects: does scanning save the object, or does it turn the object into measurable surface? Whether this is a problem seems to be dependent on the interpretative framework that surrounds the scan.

9.Case Study IV: Morehshin allahyari and Disrupted Decentralised Digital Ownership of Destroyed Heritage

3D printing and heritage the ethical case study Material Speculation: ISIS by Morehshin Allahyari Allahyari started his (re)constructions of destroyed objects in Mosul after Daesh/ISIS destroyed artefacts there in 2015, using 3D modelling and printing to do so. Her series, Wired said, featured 3D-printed replicas of items destroyed in 2015 each included a USB drive that had 3D files and historical information. In contrast, this work deploys 3D printing not as a means of replication, but rather memory, critique and resistance. (Wallis, 2017)

Allahyari s project is particularly significant insomuch as it interrogates the overly simplistic notion that digital technology can 'save' heritage. She takes issue with the assumption that corporate or institutional ownership of 3D files is preservation. The challenge is about ownership who owns the scan, who controls access to it, who monetizes the data, and who (if anyone) determines how non-existent or heretical heritage ought to be depicted. And these questions are directly linked to Oruç's argument that 3D heritage technologies could create new modalities of ownership for scans. (Oruç, 2022)

This case examines this consideration beyond the studio. And you know 3D printing can be a political platform. A replica of a destroyed thing is not that thing and cannot undo loss. However, it can serve as a mnemonic device, as an indictment against brutality, and as a call for ethical management of cultural data. This can also undermine the belief that technical reconstruction is sufficient. Heritage is not merely form but history, community, trauma, ownership and interpretation.

Alhayyari's work makes tangible the limitations of what 3D printing can do in this chapter. It can piece together what we have lost but not a process of destruction. It can circulate memory, but also create other forms of appropriation. It opens up access, but it may also reinforce inequitable power if the digitised files are in institutions outside of the communities with which the heritage is shared.

10. 3D Printing as Disruptive Technology for Sculpture and Heritage Practice

One of the most significant advantages to come from 3D printing is speed. In traditional practice, the transfer from concept to object can take time. These stages are: clay modelling, armature building, mould-making, wax casting, casting preparation, metal pouring and finally chasing and finishing all of which take time. Although 3D printing cannot remove all of these stages from the process particularly for works that will end up cast in bronze or similar material with a long lifespan it can drastically speed up ideation and prototyping. It allows artists to get from idea to physical test model. Especially when

the sculpture has some complexity or if the artist is communicating the idea to patrons, curators, fabricators, or public art committees.

The second dimension is scale adaptability. The digital file can be blown up many times, whereby the artist can prototype a piece as a small maquette, a medium sculpture, or for large installation. This could be arguably the most practical leg up you have over traditional methods. It directly addresses the fact that a handmade object has static dimensions Scale becomes, in digital practice, a variable not a limit. That does not mean that scale is artistic neutral. A three-metre sculpture is not just a large thirty-centimetre model; it is determinant in relation to body, weight, presence and architecture. Yet the technology behind 3D printing makes scaling such testing far easier.

The third aspect is formal complexity. However, this precision can also be valuable; it enables production of elements such as lattices, internal voids and inter-locking parts that would otherwise take a hand modellers time to carve or sculpt. It widens the visual vocabulary in which sculpture still might be made at present for modern artists. It enables missing components to be tested virtually and then physically manufactured for heritage restoration. According to Acke et al., 3D tech is used for virtual recreation and loss replacement within conservation-restoration processes. (Acke et al., 2021)

The fourth impact is accessibility. Museums have produced tactile replicas of delicate items so that visitors can feel shapes without putting originals at risk. Students touch 3D-printed replicas of sculptures from far-off collections. Touch helps visually impaired audiences feel volume and contour. The Swedish National Heritage Board highlights tactile and multi-sensory access as a benefit of 3D models. This is relevant to 3D printing not just for art practices but also for learning and public outreach. (Swedish National Heritage Board, n.d.)

Fifth impact: Material economy By adding material where needed instead of milling it away from a block, some kinds of waste are lessened. It may also decrease waste caused by repeating the mould failure or doing scale tests. But this advantage should not be exaggerated. These include supports, failed prints, excess resin, plastic waste, calibrations clipping machines and energy consumption. Not all processes which are digitally fabricated will necessarily be sustainable; they only become so if material choices, print planning recycling and production ethics are managed.

The sixth impact is collaboration. Within the framework of digital fabrication, new actors are integrated into the process: 3D modelers, scanning technicians, software experts, printer operators and CNC programmers/archivists. Sculpture has always been collaborative, but digital fabrication changes the nature of that expertise. Rather than being the only maker of an object, the artist can become a director of a complicated work flow. It can be liberating, but it is equally capable of separating artistic intention from material execution.

Seventy is the preservation of data. After a sculptural object has been scanned or modelled, it can be stored like a book in a library and analysed, edited and reproduced. Selected benefits of the combination technique include targeted use for origins that are fragile, endangered or otherwise inaccessible. But data preservation also presents a variety of solutions, namely the challenges of storage, file type obsolescence, metadata accuracy, ownership and consent, and access in the longer term. The meaning might be lost even when the shape holds, since a scan without contextual information can be meaningless.

11.Limitations, Drawbacks and Critical Concerns

The greatest artistic constraint that 3D printing might lose the human touch. With fine sculpture the surface bears traces of touch, bearing hand and body rhythm. It demonstrates how things were decided in the moment: where the artist pressed down too hard, where material did not cooperate, where a mistake was corrected and where a tool mark remained. These marks are more than just technical flaws. They can be emotional signs. Art accepts human error — there is vulnerability, presence, and the proof of a process. Admittedly, a 3D-printed surface has none of this intimacy—especially with mechanical finishings.

The second shortcoming is mechanical consistency. This is all a long discussion but 3D printing latches on to repetition very well. Multiple objects (the same at least in the above file). Which is, of course, an advantage for industrial production. If the work depends upon uniqueness, as indeed sculpture may

have to do, repetition becomes aesthetically suspect. For instance, most citing methods like South Indian bronze in traditional lost-wax casting generate one-of-a-kind pieces due to the breaking of the mould. In contrast, a digital file can be printed multiple times. You are not worse than anything else because of this, but it does change the ontology of the object. Instead, I am asking where the original piece is. to 'what is the official file and print? (Smithsonian National Museum of Asian Art, n.d.)

The third limitation is on material translation. A 3D model is merely representative of outer geometry, not the entirety of how bronze, stone, clay, wood and terracotta behave. Plastic that you print does not feel like bronze; resin does not weather like stone; and PLA doesn't have weight of a carved hunk of wood. The original digital surface can still come through to the final metal object, even though a print was only used as one of many steps in the process to obtain the cast. It could be a sculpture with digital smoothness as opposed to hand-modelled unevenness. According to the Swedish National Heritage Board, 3D models alone cannot communicate materiality and therefore may need material samples in addition. (Swedish National Heritage Board, n.d.)

The fourth limitation is technical dependence. Minimally, artists become dependent on the software they use to create designs, printers and technicians used to bring those designs into existence, file formats created for printing, slicing settings placed in machines (and/or computer coding), machine maintenance practices managing materiality effects while externally fabricating their sculptures. Although this may free artists to realise complexity in forms, it can bring about disjunction with material. If the artist doesn't understand the workflow, then it can very much get lost in translation and become technically impressive but conceptually lightweight. The machine should serve the idea rather than dominate it.

A fifth limitation concerns authorship. For example, in a sculpture that is fabricated digitally, the artist may provide the idea, a digital artist will create the design for a prototype, a printer will print it in 3D and produce an initial form while workers at another company might perform tasks with foundries to cast final versions of it. Ethics must recognize this collaborative chain. Collaboration is a strength, invisible work is the problem. Crediting the digital technicians, traditional artisans who determine resulting works in academic and curatorial writing.

The sixth challenge is in the domain of displacing traditional craft communities. 3D printing, focused solely on reducing labour cost; will only marginalise artisans built from generations of craftsmanship. Craft knowledge is often passed down within family and community structures, which become very important in India. It would not just be an economic loss for the disappearance of making moulds, modelling waxes, chasing by hand or carving stones or finishing bronze. It would also be a loss of embodied heritage knowledge.

A seventh concern is authenticity. While a 3D-printed replica can be practical for education, showcasing and being accessible to the public, it pales in comparison to the original. It does not retain the originality of historical time, ritual biography, material aging or provenance like that of the original. Most museums and publications need to make this clear distinction. Otherwise, it can create disambiguation between what is original, reconstruction and interpretation.

A further sixth concern is ethics and ownership. Sacred or important objects under the care of the community, religious groups or nations themselves may have to give permission for scanner access, or reproduction. Studies of Aboriginal heritage highlight communal benefits, decision-making power, custodianship and ethics; they also appear to have concerns for data sovereignty. These principles are applicable beyond Indigenous contexts. Ethical considerations Culturally sensitive artefacts including sacred images, temple sculptures and funerary objects ought to not be scanned and reproduced without ethical consultation. (Csoba DeHass et al., 2025)

A ninth concern is sustainability. Sure, additive manufacturing can eliminate some avoidable waste, but it generates a waste of its own. Errors in prints, the need for support structures and toxic resins, plastic spools and energy consumed by machines need to factor into that. Nature of the Future, your 3D printing will be better for the ecology! Your 3D printing will be great for the ecology, given responsible material choice, adaptable workflows, recyclability and restricting unnecessary production.

That does not mean to discard 3D printing. By that they mean one should use with caution. To ask the artist: Why print it, what is gained, what lost, who involved in the who owns the file and what goes into the physicality of final object and how will that object be experienced?

12. Toward a Hybrid Future: Machine Precision and Human Touch

Future sculptural work will probably not be all tradition based or all digital. The direction that is best in terms of productiveness is hybrid practice. Such a practice may start off sketching by hand, clay studies or found objects, these can be scanned into 3D computer modelling programs, prototypes printed out from the digital file as many times before adding layers, surfaces manipulated by hand-layered and ground; moulds made; final works cast in bronze, fibre, resin or other media and finishing returned to chiselling-polishing-painting-patination-installation. The digital file itself is one part within a longer sculpture process.

This creates a hybrid model that combines the best of both worlds. So it retains contact, surface sensitivity, material respect, bodily involvement and craft insight from traditional sculpture. Speed, scale flexibility, complex form-making, storage and prototyping (all virtues of digital fabrication). The end is not labour displacement; but rather redeployment of labour into more substantive artistic choices. Machines can diminish repetitive, or overly physical labor, but that should not eliminate the artist's own agency over material and meaning.

Hybrid practice is particularly valuable for heritage sculpture. For example, when a damaged object is scanned in order to capture its status. Printed test models of the parts that are missing can be digitally reconstructed. Depending on the artifact, artisans and conservators may choose to leave the reconstruction visibly different from the original piece, cast it in a compatible material or use it only for research purposes. This model allows technology to support conservation without making it seem that the print is an original. It also opens up the opportunity for many artists, conservators, historians and communities sponsored by viewers to take part in the interpretation.

Hence, contemporary art education should prepare students for this future by teaching them hand and digital methods. An only-software learner will churn out forms without understanding weight, balance, surface, and the resisting of materials. A student who is only trained in traditional ways would have a little trouble interacting with current possibilities of fabrication. A curriculum that includes clay modelling, mould-making and casting, carving, 3D scanning and digital sculpting, 3D printing, CNC processes as well as critical theory must be balanced. With technical skill come considerations of ethics and aesthetics.

We also need to rethink the very notion of the artist. The image of the solitary sculptor labouring in isolation with material is not enough. Sculpture has always been collaborative in many respects. Digital fabrication accentuates this collaboration. An artist who asks the deeper questions, makes things from those questions and then thinks about how to curate that work as an editor would; the artist as a director; the artist as a negotiated process. The challenge lies in making sure the collaboration does not eclipse the craftsperson or technician, and that technology is left as a tool rather than as an easy way out.

So, perhaps the most telling sculpture of the future is one where the digital and manual do not contest. It can provide structure; the hand, sensation. Information dies in the file; emotion exists on the surface. The prototype speeds up decision-making; the object can deepen again into matter. While the object can be data, its cultural significance might reside in the community, ritual, and memory.

13.Conclusion

This revolution in the sculptural paradigm depends on how 3D printing has changed models of form, and protypes, scale, reproduce or conserve. It has alleviated some of the defectors in conventional practice, particularly size-constraint, time dimensions correlating to prototyping and its labour-intensive forge or models moulding. It has enabled new modes of complex geometry, public sculpture, museum education, tactile access and heritage reconstruction. It has also helped speed up certain artists or visualise forms that would have been impossible, or exceedingly challenging otherwise using hand processes only.

This is not, however, a Losing Transformation. Sculpture is not simply a final object; it is an operation in touch, time, correction, bodily engagement and material negotiation. The human presence is imbued in that handmade object. All of this can become an artistic value these irregularities and errors. A mere mechanical 3D print might miss the emotion, touch warmth and random life inherent in handmade sculpture. In this light, 3D printing should not be viewed as an oracular substitute to more traditional sculptural processes.

As the case studies in this chapter illustrate, different models of engagement are available. On the ability of contemporary Indian sculpture to create productive conversations between craft traditions and 3D printing by L.N. Tallur Barry X Ball illustrates where traditional hand finishing meets modern technology. With her work, Karin Sander demonstrates that mechanical reproduction may itself become a conceptual question of portraiture, and presence. Morehshin Allahyari: 3D Printing and the Future of Memory, Destroyed Heritage and Ownership. Such examples provide some evidence that there is no sole "meaning" of technology. The artistic significance is relative and will depend on how it is used, contextualised and interpreted.

In heritage sculpture, the principal problem is to preserve object and process. A 3D scan may record external form, but it cannot fully render the hand knowledge of the practitioner, the ritual life of the object, materiality heft, or tactile cultural meaning. So sculpture of the best future is hybrid. Digital fabrication needs to make traditional skills better, not eliminate it. It should encourage conversation between artist, artisan, technician, material, file machine and the viewer.

This means that critical balance should be established when rethinking heritage sculpture using 3D printing. This is a powerful technology, but we need it to remain accountable to art. With that speed, precision, scale, and access comes a need for sensitivity, ethical responsibility, and awareness of cultural memory; machine learning can provide these things if only it is guided by the human. The power of 3D printing is not in making sculpture more machine and less human, but in creating new meeting places for human imagination, traditional craft knowledge, and the possibilities of emerging technology.

References

- Acke, L., De Vis, K., Verwulgen, S., & Verlinden, J. (2021). Survey and literature study to provide insights on the application of 3D technologies in objects conservation and restoration. Journal of Cultural Heritage, 49, 272–288. https://doi.org/10.1016/j.culher.2020.12.003
- Addison, A. C. (2000). Emerging trends in virtual heritage. IEEE Multimedia, 7(2), 22–25.
- Allahyari, M. (n.d.). Material speculation: ISIS. Retrieved May 18, 2026, from https://morehshin.com/material-speculation-isis/
- Asia InCH. (n.d.). Bronze casting of Tamil Nadu. Retrieved May 18, 2026, from https://asiainch.org/craft/bronze-casting-of-tamil-nadu/
- Balletti, C., Ballarin, M., & Guerra, F. (2017). 3D printing: State of the art and future perspectives. Journal of Cultural Heritage, 26, 172–182. https://doi.org/10.1016/j.culher.2017.02.010
- Barry X Ball Studio. (n.d.). Profile. Retrieved May 18, 2026, from https://www.barryxball.com/profile
- Benjamin, W. (2008). The work of art in the age of mechanical reproduction (J. A. Underwood, Trans.). Penguin Books. (Original work published 1935)
- Britannica. (2026). Modeling. Encyclopaedia Britannica. Retrieved May 18, 2026, from https://www.britannica.com/art/modeling-sculpture
- Britannica. (2026). Sculpture: Casting and molding. Encyclopaedia Britannica. Retrieved May 18, 2026, from https://www.britannica.com/art/sculpture/Casting-and-molding
- Campanaro, D. M., Landeschi, G., Dell'Unto, N., & Touati, A.-M. L. (2016). 3D GIS for cultural heritage restoration: A "white box" workflow. Journal of Cultural Heritage, 18, 321–332. https://doi.org/10.1016/j.culher.2015.09.006
- Csoba DeHass, M., Collins, L., Taitt, A., Raymond-Yakoubian, J., Doering, T., Ellanna, L. N., Hollinger, E., Gonzalez, J., John, E., Jr., Martinez, D., & Tapqaq, M. S. (2025). Ethical

considerations in the use of 3D technologies to preserve and perpetuate Indigenous heritage. American Antiquity, 90(2), 282–306. https://doi.org/10.1017/aaq.2024.82

- Csoba DeHass, M. K., & Taitt, A. (2018). 3D technology in collaborative heritage preservation. Museum Anthropology Review, 12(2), 120–153. https://doi.org/10.14434/MAR.V12I2.22428
- Di Giuseppantonio Di Franco, P., Galeazzi, F., & Vassallo, V. (Eds.). (2018). Authenticity and cultural heritage in the age of 3D digital reproductions. McDonald Institute for Archaeological Research.
- Elsevier. (2025). Where can I find information about Scopus' content coverage policy? Elsevier Support. Retrieved May 18, 2026, from https://www.elsevier.support/admin-tool/answer/where-can-i-find-information-about-scopus-content-coverage-policy
- Garstki, K. (2017). Virtual representation: The production of 3D digital artifacts. Journal of Archaeological Method and Theory, 24(3), 726–750. https://doi.org/10.1007/s10816-016-9285-z
- Higueras, M., Calero, A. I., & Collado-Montero, F. J. (2021). Digital 3D modeling using photogrammetry and 3D printing applied to the restoration of a Hispano-Roman architectural ornament. Digital Applications in Archaeology and Cultural Heritage, 20, Article e00179. https://doi.org/10.1016/j.daach.2021.e00179
- Jeffrey, S. (2015). Challenging heritage visualisation: Beauty, aura and democratisation. Open Archaeology, 1(1), 144–152. https://doi.org/10.1515/opar-2015-0008
- Jeffrey, S., Love, S., & Poyade, M. (2021). The digital Laocoön: Replication, narrative and authenticity. Museum & Society, 19(2), 166–183. https://doi.org/10.29311/mas.v19i2.3583
- Karin Sander Studio. (n.d.). 3D body scans. Retrieved May 18, 2026, from https://www.karinsander.de/en/work/3d-bodyscan
- Kenderdine, S., & Yip, A. (2018). The proliferation of aura: Facsimiles, authenticity and digital objects. In K. Drotner, V. Dziekan, R. Parry, & K. C. Schrøder (Eds.), The Routledge handbook of museums, media and communication (pp. 274–289). Routledge.
- Krauss, R. (1979). Sculpture in the expanded field. October, 8, 30–44. https://doi.org/10.2307/778224
- Latour, B., & Lowe, A. (2011). The migration of the aura, or how to explore the original through its facsimiles. In T. Bartscherer & R. Coover (Eds.), Switching codes: Thinking through digital technology in the humanities and the arts (pp. 275–298). University of Chicago Press. https://doi.org/10.7208/9780226038322-017
- Malik, U. S., Tissen, L. N. M., & Vermeeren, A. P. O. S. (2021). 3D reproductions of cultural heritage artifacts: Evaluation of significance and experience. Studies in Digital Heritage, 5(1), 1–29. https://doi.org/10.14434/sdh.v5i1.32323
- MoMA. (n.d.). Karin Sander. Karin Sander 1:10, 1997, 3D-bodyscan of the living person. 1997. The Museum of Modern Art. Retrieved May 18, 2026, from https://www.moma.org/collection/works/88916
- Nasher Sculpture Center. (n.d.). Barry X Ball. Retrieved May 18, 2026, from https://www.nashersculpturecenter.org/read-watch/articles/article/id/169
- National Gallery of Art. (n.d.). Explore the basics of sculpture. Retrieved May 18, 2026, from https://www.nga.gov/educational-resources/explore-basics-sculpture
- Nature Morte. (n.d.). L. N. Tallur. Retrieved May 18, 2026, from https://naturemorte.com/artists/lntallur/
- Neumüller, M., Reichinger, A., Rist, F., & Kern, C. (2014). 3D printing for cultural heritage: Preservation, accessibility, research and education. In M. Ioannides & E. Quak (Eds.), 3D research challenges in cultural heritage: A roadmap in digital heritage preservation (Lecture Notes in Computer Science, Vol. 8355, pp. 119–134). Springer. https://doi.org/10.1007/978-3-662-44630-0_9
- Oruç, P. (2022). Rethinking who "keeps" heritage: 3D technology, repatriation and copyright. GRUR International, 71(12), 1138–1146. https://doi.org/10.1093/grurint/ikac096

- Pieraccini, M., Guidi, G., & Atzeni, C. (2001). 3D digitizing of cultural heritage. Journal of Cultural Heritage, 2(1), 63–70. https://doi.org/10.1016/S1296-2074(01)01108-6
- Pye, D. (1968). The nature and art of workmanship. Cambridge University Press.
- Remondino, F., & Rizzi, A. (2010). Reality-based 3D documentation of natural and cultural heritage sites: Techniques, problems, and examples. Applied Geomatics, 2(3), 85–100. https://doi.org/10.1007/s12518-010-0025-x
- Richards-Rissetto, H., & von Schwerin, J. (2017). A catch 22 of 3D data sustainability: Lessons in 3D archaeological data management and accessibility. Digital Applications in Archaeology and Cultural Heritage, 6, 38–48. https://doi.org/10.1016/j.daach.2017.04.005
- Roued-Cunliffe, H. (2020). Open heritage data: An introduction to research, publishing and programming with open data in the heritage sector. Facet Publishing.
- Saffronart. (2024). Tallur L N: Floccinaucinihilipilification (Prototype). In Winter Online Auction, Dec. 17–18, 2024, lot 108. Retrieved May 18, 2026, from https://www.saffronart.com/auctions/postwork.aspx?l=49987
- Santana Quintero, M., Fai, S., Smith, L., Duer, A., & Barazzetti, L. (2019). Ethical framework for heritage recording specialists applying digital workflows for conservation. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-2/W15, 1063–1070. https://doi.org/10.5194/isprs-archives-XLII-2-W15-1063-2019
- Scopigno, R., Cignoni, P., Pietroni, N., Callieri, M., & Dellepiane, M. (2017). Digital fabrication techniques for cultural heritage: A survey. Computer Graphics Forum, 36(1), 6–21. https://doi.org/10.1111/cgf.12781
- Sennett, R. (2008). The craftsman. Yale University Press.
- Serenade Team. (2024). Sculpting the future: L. N. Tallur on art, innovation, and society. Serenade Magazine. Retrieved May 18, 2026, from https://serenademagazine.art/sculpting-the-future-l-n-tallur-on-art-innovation-and-society/
- Smithsonian National Museum of Asian Art. (n.d.). Bronze casting. Retrieved May 18, 2026, from https://asia-archive.si.edu/learn/india-shiva-nataraja-lord-of-the-dance/bronze-casting/
- Swedish National Heritage Board. (n.d.). 3D models: Opportunities and limitations. Retrieved May 18, 2026, from https://www.raa.se/in-english/outreach-and-exhibitions/guide-for-increased-accessibility-through-3d-models/5-3d-models-opportunities-and-limitations/
- Tate. (n.d.). Sculpture. Retrieved May 18, 2026, from https://www.tate.org.uk/art/art-terms/s/sculpture
- Trusted, M. (2007). The making of sculpture: The materials and techniques of European sculpture. V&A Publications.
- Udayakumar, S. (2014). Traditional wisdom and current practices of bronze technology in Tamil Nadu: With special reference to Tanjore District. Heritage: Journal of Multidisciplinary Studies in Archaeology, 2, 772–782.
- Victoria and Albert Museum. (2024). Sculpture techniques. Retrieved May 18, 2026, from https://www.vam.ac.uk/articles/sculpture-techniques
- Wachowiak, M. J., & Karas, B. V. (2009). 3D scanning and replication for museum and cultural heritage applications. Journal of the American Institute for Conservation, 48(2), 141–158. https://doi.org/10.1179/019713609804516992
- Wallis, F. (2017). Defying Daesh—with a 3D printer. WIRED. Retrieved May 18, 2026, from https://www.wired.com/story/defying-daesh-with-a-3d-printer/
- Yilmaz, H. M., Yakar, M., Güleç, S. A., & Dülgerler, O. N. (2007). Importance of digital close-range photogrammetry in documentation of cultural heritage. Journal of Cultural Heritage, 8(4), 428–433. https://doi.org/10.1016/j.culher.2007.07.004