

PRESERVING 3D PRINTED ARCHITECTURAL MODELS - THE HERITAGE AND CONSERVATION OF ARCHITECTURAL DESIGN PROCESS

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INTRODUCTION

Architectural models are an important part of architectural practice and culture, recording and communicating design process. Evidence of historic architectural models such as that held by the Thorp Modelmaking Archive and the internal archives of architectural practices such as Zaha Hadid Architects (ZHA), Foster + Partners, Make, and others provide valuable insights into the practices and processes that enable the development and communication of design concepts¹. These models provide a tangible record of the social, political and technological concepts that have shaped the built environment, and the craftsmanship and creativity of the architectural modelmakers who make them².

With the adoption of digital technology from the 1990s onwards, the tools and processes involved in creating architectural models rapidly developed³, with models made during the design process today heavily using 3D printing (3DP)⁴. As architectural models are increasingly archived these soon-to-be historic 3DP artefacts create new challenges for conservators.

This paper investigates the growing challenge of caring for culturally significant 3DP architectural models made by Zaha Hadid Architects, now in the collection of the Zaha Hadid Foundation (ZHF).

3D printed architectural models

Plastics started to be used for modelmaking in the late 1930s, with Perspex (PMMA) first adopted to capture the transparency of modernist architecture. By the 1950s Perspex had become the dominant modelmaking material due to its stability, durability, and ease of machining. In the 1990s digital processes such as computer-aided design and computer-aided manufacture (CAD/CAM) were adopted by commercial modelmakers and architectural practices such as ZHA⁵. Digital workflows enabled emerging digital manufacturing methods such as computer numerically controlled (CNC) machining and laser cutting to be used for architectural modelmaking. The use of 3DP in architectural modelmaking was an important milestone in the integration of digital technology and which developed in four phases:

1. Exploratory and experimental - In the late 1990s architectural firms explored 3DP as a technology for architectural modelmaking. During this period Foster + Partners commissioned a stereolithographic 3D printed presentation model of the Swiss Re concept for 30 St Mary Axe.
2. Early commercial adoption and outsourcing – By the early 2000s 3DP was becoming part of modelmaking workflows. Advances in digital design allowed for new and more complex

architectural forms to be designed, which were difficult to replicate in model form using traditional methods, thus providing an opportunity for 3DP to be more widely adopted.

Commercial prototyping firms like Materialise were producing high fidelity architectural models for competition tenders and design reviews.

3. In-house capability – by the mid-2000s architectural firms developed in-house capability through acquiring 3DP technology such as selective laser sintering (SLS) and fused deposition modelling (FDM) equipment and developing expertise in design and fabrication⁶. 3DP became a fast and efficient means of producing iterative design models during the design process. In 2008 Foster + Partners in-house 3DP department was producing 4000 models a year⁷.
4. Standard practice – From 2010 onwards digital workflows have been fully integrated into all stages of architectural modelmaking alongside more traditional means.

3DP technology is now the standard format for iterative design models made by in-house modelmaking workshops in architectural practices and is also used to create complex components in elaborate presentation models directed at clients or the public. Some architectural models are now purely digital outputs, while others integrate 3D printing. A model of the Bloomberg Headquarters Building made by 3DD Productions in 2017 included over 30,000 finely detailed components using various fabrication methods including 3D Printing⁸.

Such models should not be seen as just digital assets, as these models are part of the creative process in providing an appreciation of scale, form, and vision. These design models show developing designs and provide a valuable insight into a usually hidden part of the design process. Presentation models – the more complete architectural models – capture the finished design.

The models observed in this ZHF study are a sub-set of architectural models. These are ‘purely’ 3D printed models used for internal discussion to tangibly experience an otherwise digital model on a computer screen.

3D printed models as historic artefacts

The conservation of architectural models within heritage collections has established protocols⁹ that rely on correctly understanding the risks associated with materials and manufacture of artefacts. As a relatively recent technology, industry archives, museums and private collections face challenges in conserving 3DP models. These objects present new challenges concerning material identification, the nature of digital heritage, and the conservation and maintenance strategies of these important examples of architectural heritage.

Deterioration of heritage plastics

The conservation of historical plastics is a substantial challenge, and within the heritage sector the stability of plastic materials is often significantly overestimated¹⁰. Common issues in identifying the correct care strategy of heritage plastics include identification of plastic materials, particularly using non-invasive means¹¹, this is problematic due to the variety of materials within polymer chemistry and the blends of co-polymers, pigments, filler and other additives. The instability of some plastics leading to severe loss of condition within a short timeframe¹². Degradation occurs via mechanisms including additive migration, oxidation and hydrolysis¹³. Storage in non-reactive packing and control of relative humidity (RH), temperature and ultraviolet (UV) light exposure environmental conditions can limit deterioration.

3DP plastic materials such as Polylactic Acid (PLA), Polyethylene Terephthalate (PET), Polyamide Nylon (PA) and Acrylonitrile Butadiene Styrene (ABS) present specific challenges for conservators¹⁴. As new grades of polymers have been developed specifically for 3DP the long-term risk profiles of 3DP materials are less understood than conventional plastics¹⁵. Parameters and conditions for 3DP processes

such as selective laser sintering (SLS) have complex thermal and chemical effects on the material that impact the stability and longevity of the final object¹⁶.

Observable signs of degradation and deterioration in plastics include discolouration as well as loss of gloss and transparency¹⁷. Deformation of objects in the form of warping, crazing and delamination is also an issue. Plastic objects can become embrittled and fragile causing breakages and surface cracking. Other changes to the surface texture and appearance can occur over time as materials break down, phenomena such as 'blooming' where additives migrate to the surface are evidence of polymer degradation.

METHODOLOGY

This empirical study compares the differences between traditionally made and 3D printed architectural models¹⁸ from the ZHF collection.

A site visit by the research team was conducted at the ZHF collection in 2025. The research team compiled a report based on field notes, in-situ observations and photographs collected during the site visit. A Sample Condition Survey approach¹⁹ was taken, general observations of the collection as well as a visual inspection of sample artefacts provide the data for this survey.

Visual inspection

6 models inspected during the visit are analysed for this study:

Early traditionally made models: 3 models (A, B and C) from the 1980s and 1990s constructed using traditional architectural modelmaking techniques. This includes typical construction methods and materials (including plastics).

Later 3D printed models: 3 'sets' of models (X, Y and Z) constructed using 3D printing technology from the 2010s were inspected.

Each model in this study was inspected directly by the research team. Notes were made on materials, current condition and deterioration e.g. discolouration, embrittlement, breakage. The inspection was non-invasive observation only to determine likely identity of materials and evidence of any degradation.

Materials risk profiles

Common degradation profiles for the materials used. Because materials were identified from archive labels and characteristics of the objects (size, material finish, and geometry) during the visual inspection, materials are unconfirmed by analytical testing by the research team.

RESULTS

ZHF Observations

The ZHF collection is stored in a three-storey former banana warehouse beside the Thames. Temperature and humidity are monitored, and while the building lacks dedicated climate control the ZHF team minimise fluctuations in RH and temperature that could stress plastic artefacts. UV-filter film and blinds have been applied to large windows, reducing light exposure. Objects in the collection are stored away from these windows to further reduce risk of damage by light. The building is shared with another tenant, pest risks and shared-use activity are actively managed.

The ZHF team combines research and preventative care of the objects within the collection that includes both personal items and artefacts from ZHA. The extensive collection is in the process of being inventoried. All items have been assessed and prioritised so that legacy materials can be replaced with archival packing such as archival boxes and inert foam. The building is in the process of being upgraded to provide enhanced racking, storage, and longer-term environmental control.

Sample condition survey

An overview of the inspected models is provided in Table 1. The observed conditions were rated by the research team using a standard index²⁰

ID	Name/description	year	type	material	Observed condition
A	The Peak, Hong Kong, China	c. 1983	Presentation Model	Various incl. polystyrene.	Good
B	Music Video Pavilion, Groningen, The Netherlands	c. 1990	Study Model	Various incl. PMMA	Good
C	Vitra Fire Station, Weil am Rhein, Germany	c. 1993	Presentation Model	PMMA	Good
X	University of Cyprus, Department of Biological Sciences, Aglandjia, Cyprus	c. 2013	-	White Nylon	Fair: Discoloured, breakages
Y	Al Janoub Stadium, Al-Wakrah, Qatar	c. 2013	Study Models	White Nylon	Fair: Discoloured
Z	Mathematics: The Winton Gallery, Science Museum, London, UK	c. 2014	-	Nylon	Fair: Discoloured. breakages

Table 1. Sample condition Survey results

Model A: The Peak (1983)



Figure 1. The Peak architectural model and archival packing. Photograph by the author, ZHF Archive, June 2025. Courtesy of ZHF

Figure 1 shows The Peak presentation model, the design is of a horizontal skyscraper that was commissioned but never built. Believed to be the earliest model in the collection. Referred to as one of their star objects which is anticipated to be in demand for exhibitions. Packaged in a custom-made archival box made from archival buffered board for both storage and for travel to exhibitions. This looked to be a well looked after object. The model looked to be in good condition, without cracks or damage.

Model B: Music Video Pavilion (1990)



Figure 2. Music Video Pavilion architectural model in Perspex case. Photograph by the author, ZHF Archive, June 2025. Courtesy of ZHF

Figure 2 is of the Music Video Pavilion study model, including a swatch of the colour pallet. The colours on the objects differ from the colour swatch legend on the base indicating some discolouration. The PMMA case is in good condition. The model is placed on protective plastazote® (low-density polyethylene foam) sheet and covered with Tyvek® (high-density polyethylene material) for protection. To protect against degradation in general environment, the model is in the process of being repacked into an archival box which is being prepared to replace non-archival packaging.

Model C: Vitra Fire Station (1993)



Figure 3. Vitra Fire Station presentation model. Photograph by the author, Zaha Hadid Foundation Archive, June 2025. Courtesy of ZHF

Figure 3 shows the Vitra Fire Station presentation model, the project was significant as it was Zaha Hadid's first completed building. The model is fragile but in good condition. The PMMA case looks discoloured (not transparent). Metal screws/hinges and case construction are a potential source of degradation. Model is packed in protective box made of archival card and plastazote® inserts to support the model.

Model X: University of Cyprus (2013)



Figure 4. Left, five 3D printed models for University of Cyprus project, Right, model breakage at stem. Photograph by the author, Zaha Hadid Foundation Archive, June 2025. Courtesy of ZHF

The collection of models in Figure 4 are of ZHA concepts for University of Cyprus. Models have become discoloured over time - internal material at break shows originally white rather than beige. The models are very fragile and several of the models are broken at the stems.

Breakages indicate that the models may have become more brittle over time. Damage occurred from previous nonarchival packing. Currently stored in plastic storage polypropylene (PP) containers with foam insert on the base, the ZHF team are in currently creating new packaging to prevent further damage. Plastazote cutouts will prevent the models from moving the box while minimising pressure being put on the objects.

Model Y: Al Janoub Stadium (2013) models



Figure 5, Collection of 9 Study models from Al Janoub Stadium project packed in acid free paper. Photograph by the author, ZHF Archive, June 2025. Courtesy of ZHF

A collection of study models in Figure 5 are ZHA stadium concepts for the Al Janoub Stadium. Each artefact has lost the original bright white colour expected of SLS prints. However, discolouration is

different on each object – some more yellow and some more grey. Original storage conditions could have contributed to variable discolouration across the samples.

Models are protected in acid free paper and stored in plastic storage (PP) containers.

Model Z: Mathematics: The Winton Gallery, Science Museum (2014)



Figure 6, 3D printed models of geometric forms and aeroplanes from Mathematics: The Winton Gallery, Science Museum project. Photograph by the author, ZHF Archive, June 2025. Courtesy of ZHF

Figure 6 shows six SLS 3D-printed models from the Mathematics: The Winton Gallery, Science Museum project, stored in plastic storage (PP) containers with foam base inserts and acid-free paper over the models. The models may have discoloured over time (probably originally white rather than beige). Dark grey models show white marks on the surfaces, possibly indicating degradation or damage. These models demonstrate complex geometry and thin features enabled by 3DP. Thin sections of the aeroplane models have started to break—see Figure 6 lower wing.

DISCUSSION

While improvements can be made to the storage environment, the 30–40-year-old traditional models were in good condition and are well managed using appropriate best practice conservation. There were signs of aging such as faded colours and PMMA losing its glass like transparency, but the traditional models appeared stable.

The 10-year-old 3DP models X, Y and Z have been cared for using similar practices but are showing signs of deterioration, discolouration and breakages.

Modes of deterioration

Deterioration prior to the ZHF care is a significant factor in the current condition of artefacts X, Y and Z – particularly the breakage seen on model X where packing by the architectural office was not to archival standards.

Although efforts are made to stabilise the storage environment, building improvements are ongoing, and natural fluctuations in temperature and humidity contribute to the ageing of the 3DP objects.

3D printed model conservation challenges

The samples inspected represent a small number of models within the ZHF collection. Many models remain stored as packed by the ZHA team and are currently being archived. The care of heritage plastics is complex, and key challenges include:

- Identifying materials – A breakdown of polymer chemistry would help identify specific plastic grades, and any additives or contaminants (e.g. cleaning or surface coatings), to assess risk factors for deterioration.
- Characterising physical properties – Surface hardness, density and porosity of 3DP objects inform fragility and support improved handling and storage.
- Storage and exhibition activities – To slow degradation, effective management during storage, handling and display is essential. Object stability requires monitoring, and light, RH and temperature conditions for PA objects require active management.
- Thin features enabled by 3DP – Highly detailed CAD models enabled ZHA to 3D print high-fidelity models. Models X, Y and Z have fine detail and thin sections that have become increasingly fragile with age.

Recording and preserving digital heritage also presents challenges: while the CAD model exists as a digital record, the printed models are important design outputs and will eventually deteriorate.

Many architectural models combine traditional and 3DP components. Evidence in this study suggests 3DP nylon deteriorates more quickly than traditional modelmaking materials, creating future challenges for repairing otherwise stable mixed-material models.

Recommendations

Based on the samples observed being typical of 3DP models in the collection, the following recommendations are made for the ongoing care and maintenance of the ZHF 3DP architectural model collection:

- Due to the nature of the SLS nylon materials, there is a risk of further deterioration. The ZHF objects that are purely 3DP models like the ones observed in this study should have increased priority in terms of archiving, packing and monitoring.
- Non-invasive analytical testing can enable detailed condition reporting. It is recommended that methods such as portable FTIR can be used to confirm the identity of materials for objects considered at greatest risk²¹. Additional non-invasive measurements such as digital microscopy, colourimeter and gloss measurements can also be conducted on site at ZHF. Objects should be kept in a controlled environment until specific preventive conservation actions can be outlined.
- During transport and handling for activities such as exhibitions, physical maintenance repair kits²² for 3D printed objects could mitigate damage.
- The wider use of 3D printing in architectural models which use other materials and processes needs further research. Modelmakers have a detailed understanding of the materials and processes used and their involvement in conservation of these models is recommended.
- Creation of a digital-physical registry to link printed artefacts to their CAD origin.

CONCLUSION

Architectural modelmaking was an early adopter of 3D printing technology. The models examined in this research provide a valuable test case for the broader category of 3D-printed heritage artefacts and their conservation. Six models were inspected, showing a clear contrast in preservation state: the earlier, traditionally crafted models remain more stable, while the 3D-printed models display a range of deterioration issues. This difference is strongly linked to material histories. Older models produced using plastics such as PMMA and polystyrene—materials with long-established use—show better long-term stability. By comparison, the more recent models were produced using then-innovative 3D-printing materials, often commercialised rapidly and potentially containing unknown fillers or additives intended to improve printability and mechanical performance. These materials now show more significant deterioration.

In particular, 3D-printed nylon remains insufficiently understood in long-term heritage contexts. Its hygroscopic nature and sensitivity to environmental conditions can contribute to embrittlement, surface change, and breakage, risks intensified by thin, intricate geometries typical of SLS components. As reliance on 3D printing in architectural practice grows, developing stronger analytical frameworks for ageing behaviour will be essential to preserve these models alongside traditionally crafted counterparts.

Acknowledgements

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NOTES

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- ⁴ This paper refers to the additive manufacturing methods used for model making as 3D printing (3DP), prior to this term, Rapid Prototyping (RP) was used for this technology.
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