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The use of photogrammetry in the conservation of painted outdoor sculpture

Adressing Jean Dubuffet's Jardin d'Email

Watkins, A.; Kensche, S.; Stigter, S.; Waagen, J.; Lanjouw, T.

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DIE NEUE
DESIGN
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FUTURE TALKS

019

**SURFACES.
LECTURES AND WORKSHOPS ON TECHNOLOGY
AND CONSERVATION OF THE MODERN**

**TIM BECHTHOLD
EDITOR**

**THEY'VE GOT PLASTIC
CHRISTMAS TREES NOW.
THEY'RE HARD
TO TELL FROM THE
REAL ALUMINUM ONES.
MILTON BERLE**

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PREFACE

"We're all like little ants who scurry around with the materials that are at hand right now. Each generation finds new materials. It's just evolution, isn't it?"

Beth Orton

This quote highlights the leading interest of our conservation department, and thus the core theme of the FUTURE TALKS: The characterisation and change of material and technologies in design and art of the 20th and 21st centuries.

Naturally, this topic is first approached superficially, i.e. from the surface. Both the user of a design object – let's take an armchair upholstered in imitation leather from the 1930s as an example (*read p. 30*) - and the art collector with a penchant for hyperrealistic sculptures (*read p. 164*), derive their enthusiasm essentially from the design and materiality of the surface materials; be they PVC as in the former case or finely structured silicones in the latter example.

THE SURFACE AS A DESIGNED INTERFACE BETWEEN OBJECT AND ENVIRONMENT

It is no wonder that the conservator's attention is also essentially focused on the surface appearance of the object. Here not only are traces of manufacture readable; the investigative expert's eye can also recognise characteristic structures of use and ageing.

THE SURFACE AS AN INFORMATION CARRIER

Reading and understanding the surface is thus the basic prerequisite for an adequate conception of suitable conservation and restoration measures.

THE SURFACE AS ELEMENTARY BASIS FOR DECISION-MAKING

Now no one should wonder why we made the topic of surfaces the focus of the FUTURE TALKS 019 conference, held from October 23 to 25, 2019.

AFTER 5 PREVIOUS CONFERENCES, THIS WAS TO BE THE MOST SUCCESSFUL EVENT IN OUR SERIES SO FAR.

With 300 participants from 26 nations a great deal of international interest could be noticed, the content of which has been condensed in this book. The present post-prints can also be read as an indicator for current research projects and an increasing expertise worldwide.

THE FUTURE TALKS 019 CONFERENCE WAS A COLOURFUL – THIS TIME – A RED BOUQUET OF:

11 speed lectures, 26 talks, 1 keynote, 1 panel talk, 1 speed mentoring session, an impressive list of 20 different workshops spots where the participant could experience the challenging nature of surfaces and not to forget our legendary evening reception at one of Munich's most futuristic spots the BLITZ Club.

THIS PROGRAMME WAS OUR MOST AMBITIOUS SO FAR

As mentioned above the quality and the success of a conservation treatment is closely connected to a deeper understanding of technology and material and thus with a broad network of different sparring partners. Unfortunately, the voice of the designer is still too often neglected. A somehow surprising fact, given that both designers and conservators are circling on similar questions: the material and the technology.

In this context we were delighted to have a Keynote from Christiane Sauer, architect and professor for materials and design at the Weissensee School of Art and Design in Berlin. Christiane Sauer gave us exciting insights into experimental material research.

Another highlight was the Panel Talk between Simone Farresin, one of the two protagonists of Studio Forma-Fantasma and Sarah Dorckenwald, designer, essayist and design theorist. This talk illuminated the Oeuvre of the Amsterdam based studio which is internationally reknown for their use of provocative experimental materials, investigations and explorations in the creation of design. This conversation is still available at our homepage at:

<https://dnstdm.de/publictalk-studioformafantasma/>

Another brilliant occasion to broaden the network was the Speed Mentoring Session. Here participants of the conference could meet and chat with 10 established professionals in short term slots (*read p. 270*).

The present post-prints are the comprehensive compilation of the FUTURE TALKS 019 conference. As always you'll find useful information related to authors, material suppliers and literature references in this compendium.

Together with the last five editions, this book provides a perfect insight into important research projects and relevant topics on the conservation of the modern over the last 10 years.

Die Neue Sammlung as a museum is happy and very grateful for this FUTURE TALKS formate. Here the scientific research of our house meets for an international exchange with experts and personalities of conservation and design and finds increasing public communication. The questions about material and technologies in design and art of the 20th and 21st centuries are as important for our museum as the presentation of objects.

The idea, concept and realisation of the FUTURE TALKS lies in the hands of Tim Bechthold, Head of our Conservation Department. To him and his team Julia Demeter, Helena Ernst and Christian Huber great thanks to their profound commitment and perfect execution this conference series came to life and ever-lasting youth.

It is moving and quite motivating that after ten years the idea and the formate of this event is not just alive but still growing. We are very grateful for this!

This conference / publication wouldn't have been possible without the support of the following people and institutions. Therefore we would like to thank:

The editorial board which invested a lot of spare time and enthusiasm to contribute considerably to the quality of this book.

All authors for providing their interesting contributions and the patience to keep the ball, even if it took sometimes longer than expected.

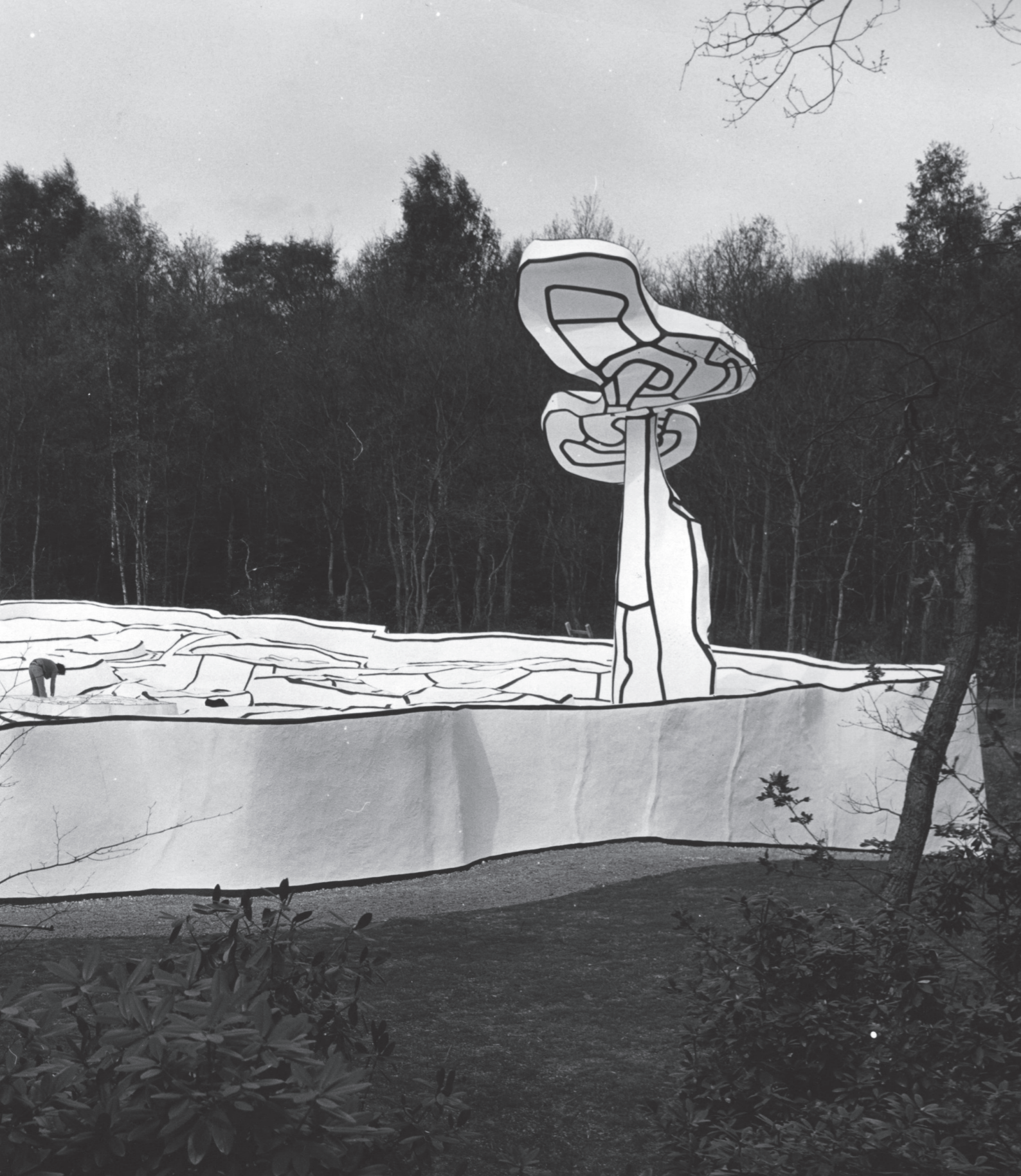
Felix Kempf. His visual design of the FUTURE TALKS has created a strong and memorable corporate identity; that this publication is not just another collection of scientific papers.

Last but not least to our sponsors and their generous support: Wuestenrot Stiftung, Schoofsche Stiftung, Deffner und Johann, Kremer Pigmente, Quittenbaum and Plank.

By the time this publication appears, the seventh conference – »FUTURE TALKS 021. Smart Solutions in the Conservation of the Modern« - will already be underway. In view of the Corona pandemic, this time in a digital format.

It is helpful to have this alternative but we are all looking forward to welcoming you back in real life next time at the FUTURE TALKS 023!

ANGELIKA NOLLERT
DIRECTOR GENERAL, DIE NEUE SAMMLUNG
THE DESIGN MUSEUM



LECTURE

004

THE USE OF PHOTOGRAMMETRY IN THE CONSERVATION OF PAINTED OUTDOOR SCULPTURE: ASSESSING JEAN DUBUFFET'S JARDIN D'EMAIL

BY ALICE WATKINS, SUSANNE KENSCHÉ, SANNEKE STIGTER, JITTE WAAGEN, TIJM LANJOUW

ABSTRACT

This research evaluates the use of innovative imaging technologies to aid the conservation of large-scale contemporary painted outdoor sculpture. It explores photogrammetry and image-based 3D modelling as tools during the conservation of *Jardin d'Émail* (1974) by Jean Dubuffet (1901-1985), owned by the Kröller-Müller Museum.

In partnership with the 4D Research Lab at the University of Amsterdam, 3D digital models of the sculpture and two scale-models were created.

This research assesses the effectiveness of using 3D digital models to inform the repainting of the sculpture's black lines on white background as part of the treatment process. The use of photogrammetry to document the patterns and forms of the sculpture and scale-models is also evaluated. The creation of 3D digital models from the photogrammetric data allows for deviation analysis to be carried out, highlighting where areas of the scale-model and sculpture deviate significantly. The 3D models were uploaded on an app for use on tablets to enable responsive access during treatment. This research showed that photogrammetry is not only useful for large scale sculpture documentation, but can also aid the treatment of outdoor sculpture by producing geometrically accurate representations of the scale-model to be used as a reference during repainting.

KEYWORDS

Photogrammetry, image-based modelling, structure-from-motion, painted outdoor sculpture, Jean Dubuffet

INTRODUCTION

Painted outdoor sculpture is under constant threat by the outdoor environment, meaning that repainting is often a necessary part of conservation maintenance (*Beerkens and Learner 2014*). Before carrying out such a treatment, documentation of the original state is highly important to act as a reference for repainting. However, the documentation of outdoor sculptures can be a challenging task, especially when the sculpture is extremely large, has a textured surface, or has harder-to-reach areas.

A sculpture which displays these issues is *Jardin d'Émail* (1974) by Jean Dubuffet (1901-1985). The sculpture is painted white with hand-painted black markings based on the design of a 1:10 scale-model made by the artist. At 600 m² it is one of the largest hand-painted sculptures in Europe which visitors can enter and walk on. Due to this interactive feature and exposure to the outdoor environment, it has a known history of overpainting. The conservation treatment in 2019 stripped back years of overpaint, revealing original hand-painted markings.⁽¹⁾ It is intended that the sculpture is repainted based on the design of the scale-model. Documenting the found markings and scale-model is crucial for ensuring repainting is as accurate as possible to Dubuffet's intended design. Similarly, the documentation should function as a practical tool when it comes to repainting.

A solution to the issue of documenting outdoor sculpture for repainting can be met with innovative technologies such as photogrammetry, which uses photographs to create 3D models. This technique is being used more frequently in the heritage sector as the main piece of hardware (a reliable digital camera) is becoming more affordable. The objective of this research is to see how photogrammetry can aid treatment decision-making of repainting *Jardin d'Émail*.

JARDIN D'EMAIL

Jean Dubuffet's *Jardin d'Émail* (*Figure 1*) is an interactive outdoor sculpture that was first envisioned by the artist in a scale-model made of glass-fibre reinforced polyester in 1968. The scale-model depicts an elevated white terrain covered by a network of black lines (*Figure 2*). In 1969, plans were made for a 1:10 enlargement of the scale-model to a sculpture at the Kröller-Müller Museum. For the enlargement, Dubuffet worked with architect Joël Poilpré to ensure that the idea and design copied the scale-model from 1968 as close as possible. An architectural model was made, depicting the necessary elevations for the sculpture (*Figure 2*).⁽²⁾ The main structure of the sculpture



Figure 1
Jean Dubuffet, *Jardin d'email*, 1974, 800 x 2000 x 3000 cm (600m²),
collection Kröller-Müller Museum.
Photograph: Kröller-Müller Museum, unknown.
© VG Bild-Kunst, Bonn 2021

is made with concrete and cement, which is coated in white paint. To paint the black lines, the scale-model was placed in the centre of the sculpture as a reference. Dubuffet's assistants Richard Dhoedt and Ali Boukhalfa first traced the position of the lines thinly with chalk and then a brush, before painting over them again (Breder 2006) (Figure 3). Dhoedt stated in an interview 'the lines may not be too tight but should be visible with the brush in a picturesque but accurate manner. The lines must support the shapes of the sculpture.' (Stigter 2006: 41).

Jardin d'email requires regular care and has been repainted three times in the 44 years since its creation. During these repaints, the black lines shifted or in some areas were missing entirely. When the sculpture was repainted in 1999 masking tape was used as a guide for the black lines, and so the impression that they were made using a paintbrush and free hand was lost (Breder 2006). In 2019, the Kröller-Müller Museum undertook a new restoration project in which all the paint was removed, revealing original hand-painted markings (Figure 4).

CURRENT STATE OF RESEARCH CONSERVATION PRACTICE OF PAINTED OUTDOOR SCULPTURE

Frederike Breder's thesis 'Außenskulpturen mit Farbfassung' (Breder 2006) focuses on the restorative treatment of contemporary painted outdoor sculpture, of which Dubuffet's *Jardin d'email* is a case-study. In it, Breder references the issues that can come from repainting when the artist's wishes have faded from memory, and the shifted black lines of the sculpture. Breder's research highlights the problems that can occur without access to good documentation and states the need for conservation to repaint the sculpture using the scale-model and archival photographs. Breder also found that the original 1974 lines match the scale-model very accurately.

Derek Pullen and Jackie Heuman give a comprehensive outline of developments in modern outdoor sculpture conservation in 'Modern and Contemporary Outdoor Sculpture Conservation: Challenges and Advances' (Pullen and Heuman, 2007). They state that the documentation methods of photogrammetry



Figure 2a / left
Jean Dubuffet, Maquette '*Jardin d'email*', 1972-1973, 80 x 200 x 300 cm (1:10 scale),
collection Kröller-Müller Museum. Photograph: Kröller-Müller Museum Archives, unknown.
© VG Bild-Kunst, Bonn 2021



Figure 2b / right
Joel Poilpré, Architectural Model / Working Model, 1973, 80 x 200 x 300 cm (1:10 scale),
collection Kröller-Müller Museum. Photograph: Alice Watkins, 5 September 2018.

and laser scanning are currently being explored and highlight the utility of these approaches in improving treatment records for individual sculptures (Pullen and Heuman, 2007: 9).

Major issues facing outdoor sculpture and what is required for their conservation has been outlined in 'Contemporary Outdoor Sculpture: Challenges and Advances,' (Beerkens and Learner 2014) stating that maintenance and repainting is often necessary. Gwynne Ryan of the Hirshhorn Museum discusses how the repainting cycles of outdoor painted sculpture allow for reevaluation of past treatments to occur. (Ryan 2014: 10). The importance of documentation is also stressed. Julia Lütolf and Peter von Bartheld call for a form of documentation that describes the process of producing an artwork as precisely as possible (Lütolf and von Bartheld 2014: 81).

Issues specific to painted outdoor sculpture have been broadly examined in 'Conserving Outdoor Sculpture' (Considine, 2010). The challenges involved with conserving painted outdoor sculpture are listed within to include: determining original appearance, understanding the artist's intent and communicating

colour (Considine, 2010: 125). Within all the case studies, a collaborative approach to repainting is stressed which involves conservators, curators, the artist estate and paint manufacturers. Although most case studies focus on choosing the correct colour than recreating hand-painted patterns, questions about original appearance and artist's intent are relevant. These issues surrounding the conservation of painted outdoor sculpture are widely acknowledged, however the use of photogrammetry to help with treatment options has so far not been discussed in detail.

PHOTOGRAMMETRY AND IMAGE-BASED MODELLING

To create a 3D model using photogrammetry, a series of overlapping images of the subject is taken. These images are then uploaded into software that uses advanced image analysis algorithms to reconstruct camera angle and position (Waagen and Lanjouw 2018). Whilst this technique has not been commonly used for contemporary outdoor sculpture, it is increasingly being used as a method of documentation in other heritage sectors such as archaeology and historical interiors.



Figure 3
One of Dubuffet's assistants painting the black lines.
Photograph: Kröller-Müller Museum Archives, 1974.

Historic England's 'Photogrammetric Applications for Cultural Heritage' gives an explanation into the general workflow that must be taken in order to achieve a 3D model, explaining the main concepts, skills, issues and challenges that a heritage professional will encounter by using photogrammetry (*Historic England 2017*). This publication is useful for this research in proving that there are both benefits and drawbacks to using this technique for conservation. The level of detail needed to capture the faint black lines of *Jardin d'émmail* may be higher than some other heritage needs, and so it will be beneficial to see how this technique can be useful for the conservation of contemporary hand-painted sculpture.

OBJECTIVE AND QUESTIONS

The objective of this research is to assess the use of photogrammetry for the treatment of painted outdoor sculpture in two phases. First, in exploring its capabilities for advanced documentation. Second, to see how the photogrammetric data can then be used practically for treatment. The following questions

will be answered: How can photogrammetry be used to inform conservation practice of painted outdoor sculptures?

- *Can photogrammetry accurately capture the original pattern?*
- *How can it inform treatment decision-making?*
- *What are the strengths and weaknesses of using photogrammetry in conservation practice?*

EXPERIMENTAL METHODS AND RESULTS

To assess the utility of photogrammetry for the treatment of large outdoor sculpture, a multi-disciplinary methodological approach was undertaken. Literature and archival research investigated photogrammetry and image-based modelling, painted outdoor sculpture and Dubuffet's oeuvre.

To understand the art-making process, interviews were carried out between the head conservator of sculpture and modern art at the Kröller-Müller Museum, Susanne Kensche and Dubuffet's assistant, Richard Dhoedt, for which the author was present. An interview was also conducted between the author and Susanne

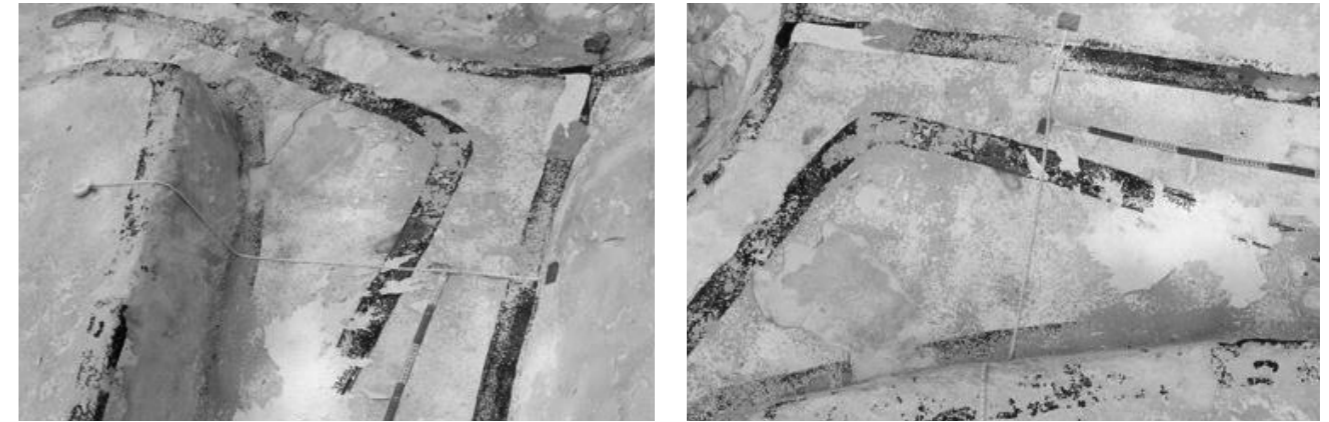


Figure 4
Original black lines found on *Jardin d'émmail*.
Photographs: Susanne Kensche, 2017.

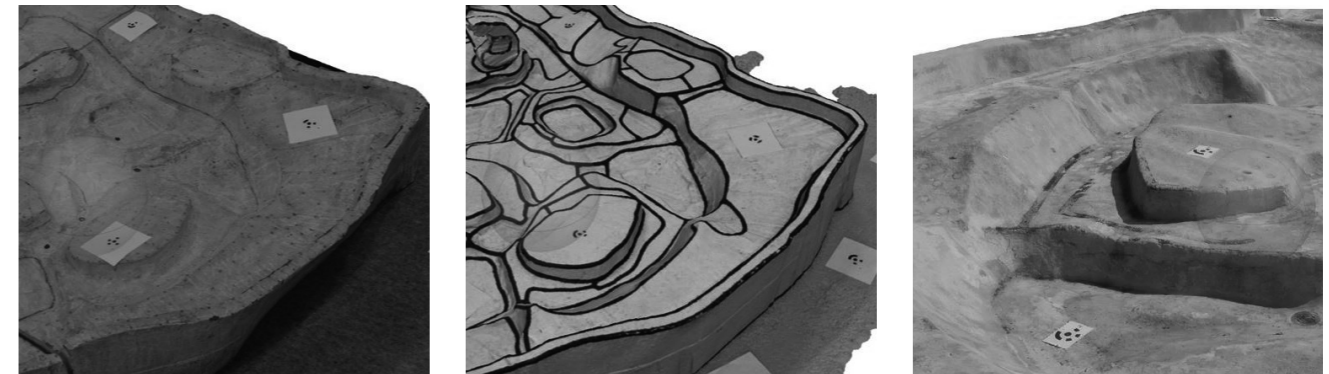


Figure 5
A section of the 3D model of the architectural model, scale-model and sculpture made with Agisoft Metashape. Credit: Tijm Lanjouw, October 2018.

Kensche, to ensure that this research produces a useful tool for the museum. From these interviews it was found that photogrammetry could benefit the 2019 treatment of *Jardin d'émmail*. The use of a portable, 3D digital model could be used during the repainting treatment. Dubuffet's assistant Dhoedt explained that during the painting of the lines in 1974 it was a struggle that they only had one model acting as a reference. He explained that it was difficult to have to keep going back and forth to the model. ⁽³⁾ This further clarified to Susanne Kensche that photogrammetry will help the museum effectively work on the sculpture and not miss out any lines, as was done previously. ⁽⁴⁾

THE PROCESS OF CREATING A PHOTOGRAMMETRIC MODEL

The practical application of photogrammetry and image-based modelling is conducted in partnership with the 4D Research Lab of the University of Amsterdam. The following section outlines the aim, method and results of the experimental process.

To begin, aerial images were taken of *Jardin d'émmail* with a

drone by Jitte Waagen. The scale-model and architectural model were photographed with an SLR camera by Tijm Lanjouw. This is the first step in creating a scanned photogrammetric model of both the outdoor sculpture and scale-models.

In preparation for the photogrammetric scan, printable targets were placed on the sculpture, scale-model and architectural model and around their perimeters. For *Jardin d'émmail*, a DJI Phantom 3 drone was used which has a camera attached to its base, controlled by a tablet attached to a control pad. Using the tablet, the ISO and shutter speed of the camera were set to automatic. A test flight was carried out to ensure the images captured were of good quality and that there was no distortion. The drone was flown at two altitudes above the sculpture, detailed shots were taken at 2.80 m, whilst an overview shot was taken at 8.25 m. The drone stopped to take a photograph every meter. Oblique and angled photographs were also taken to capture the surface structure and the perimeter of the sculpture. For the scale-model and architectural model, a Nikon D5300 was attached to a stabilisation pole. After ensuring that the white

balance and shutter speed were appropriately set and the model was in focus, a series of overlapping photographs were taken in aerial and oblique view, at a distance of 1 m (+/- 10 cm).

POST-PROCESSING RESULTS USING AGISOFT METASHAPE

3D models of *Jardin d'email*, the scale-model and the architectural model were made by Jitte Waagen and Tijm Lanjouw. Analysis of these 3D models can help the treatment process, as any deviation in the surface structure between the scale-model and outdoor sculpture can be highlighted.

The photographs taken of the sculpture, scale-model and architectural model were first checked to ensure all images were in focus with appropriate lighting. The images were then imported into Agisoft Metashape which makes an estimation of image quality. To begin, alignment optimisation is carried out to detect the markers (targets) and correct their position. The software then calculates camera position and location and identifies the tie-points.⁽⁵⁾ A sparse point cloud is generated.⁽⁶⁾ The cameras are then optimised, and the reprojection error is calculated.⁽⁷⁾ A dense point cloud can then be formed, followed by a mesh, onto which the texture can be applied. At this point the 3D model has been made and can be exported for further analysis.

The results of the modelling process proved photogrammetry can capture the original pattern of the uncovered black lines. This is possible because of the 0.2 cm resolution that photogrammetry offers (every pixel is covering 2 mm of the object) which gives a high accuracy of the captured geometry. The reprojection error is the average error between a measured point in a 3D model and the projected point on an image. The error was computed to be only 1.2 pixel when expressed in image distance, which indicates that the 3D model is a very close representation of the artwork. The resulting 3D models are highly accurate and detailed (*Figure 5*). Agisoft Metashape allows for 3D models to be exported in various formats that are accessible on a range of devices and platforms. As such, this enables the museum to have a clear and detailed view of the scale-model to help with the repainting process, therefore informing treatment decision-making.

DEVIATION ANALYSIS WITH CLOUDCOMPARE

Once a 3D model is made it can undergo further analysis. As the scale-model is intended to be used for the repainting of the black lines it was important to know if there were any deviations between it and the sculpture, which would influence treatment decision-making.

CloudCompare is an open-source software that enables the point clouds of two different 3D models to be analysed for deviation and similarities (CloudCompare, n.d.). Deviation analysis between the 3D models was carried out by Tijm Lanjouw, in the following sequences; (FIRST) the scale-model and architectural model, (SECOND) the scale-model and outdoor sculpture and (THIRD) the architectural model and the outdoor sculpture.

To compare the point clouds, they are first aligned. This means manually moving the second model onto the same position as the first model. For the comparison between the scale-model, architectural model and the outdoor sculpture, the two models were scaled up to match the size of the sculpture. CloudCompare then automatically aligns the two point clouds to find a best fit.

CloudCompare then calculates the distance between the two point clouds. The result shows any deviation between two aligned models. The software finally generates a heat-map indicating the areas of similarity and deviation.

This detailed deviation analysis allows for more information about the making-process, the sculpture's material history and for problem areas to be highlighted. A visual inspection between the scale-model and architectural model shows the two models to be made from the same mould, or the same cast. This sheds light on how far the model used for the building of the sculpture is based on the model used for painting the lines. Deviation analysis between the sculpture and the two models showed that in general, the sculpture closely follows the shape of both models, with over half of the models only deviating between 0-3 cm from the sculpture (*Figure 6a*). However, a large difference between the scale-model and the sculpture can be observed in the centre-north region. Here the scale-model deviates by an elevation upwards of 30cm from the sculpture (*Figure 6b*). This result will certainly inform treatment decision-making, as problem areas such as this can be noted before repainting begins.

TESTING 3D MODEL ON SCULPTURE WITH THE APP 'EMB3D'

Uploading the 3D scale-model onto the open source app Emb3d provides a practical and portable reference tool for the repainting process. Emb3d is accessible on both mobile and tablet. The physical scale-model is used for repainting the black lines on *Jardin d'email*, so access to a digital version should make the process more efficient.

The 3D reconstruction of the scale model was uploaded to Emb3d, which enables the offline viewing of 3D models on a tablet or phone (Emb3d, n.d.). The digital model was taken to the sculpture, so its use in the repainting process could be evaluated. To test the tool, lines were drawn onto the sculpture in charcoal using the 3D model on the tablet as a reference. The technique was evaluated on accuracy, how long it took, and whether it was possible to estimate line thickness, angle and position. General strengths and weaknesses of the approach were also noted. The drawing of the test lines was carried out by the author and fellow trainee conservator Laura Wolfkamp of the University of Amsterdam.

Testing the 3D model on the sculpture allowed for a practical assessment of the technique. It was found that treatment decision-making is improved, as the conservator can make a direct comparison to the digitised scale-model in their hand. Therefore, they are able to immediately correct mistakes from deviating from the course of the scale-model. Equally, more

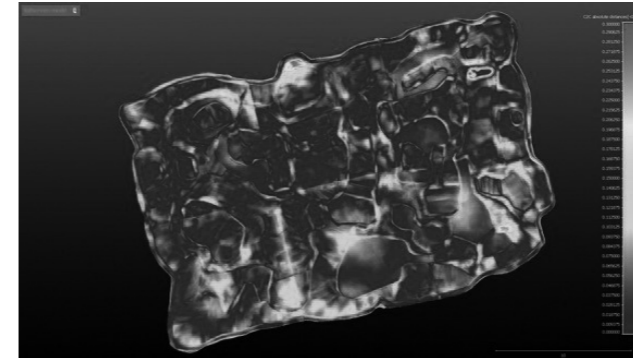


Figure 6a
Deviation analysis between *Jardin d'email* and the architectural model using CloudCompare.
Credit: Tijm Lanjouw, November 2018.
see colour plates

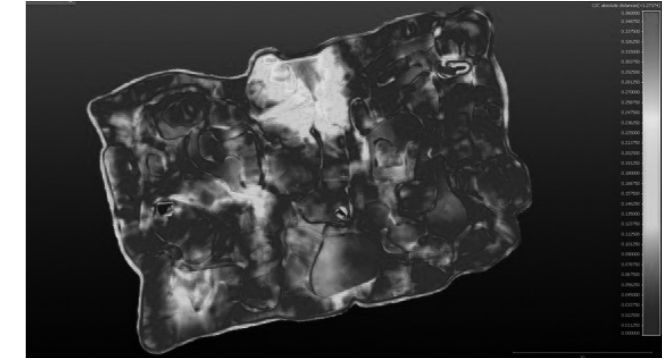


Figure 6b
Deviation analysis between *Jardin d'email* and the scale-model using CloudCompare.
Credit: Tijm Lanjouw, November 2018.
see colour plates

points of view are possible than with the original scale-model. For instance, the conservator can stand on an area of the sculpture they are aiming to paint on, and at the same time view a zoomed-in birds-eye-view of this area.

However, it was found that it is possible to look at the tablet too much, meaning that the painted line can risk not flowing as Dubuffet would have wanted. Similarly, it can be difficult to judge the edges of the model, particularly how far the line overlaps a corner. As the scale-model was found to be not the same as the sculpture it can also be difficult to see where the line should go, and as a result accuracy is not improved. A suggested improvement for the 3D model which could increase accuracy is to include a scale-bar that can indicate how thick the lines should be.

It was noted that different people work in different ways, and that one conservator may prefer to use the original scale-model over the 3D model on the tablet. New digital tools and approaches can enhance treatments, but the 'affordability' of digital equipment is an issue to keep in mind (*Morgan & Wright*

2018). Overall, having the 3D model on the tablet has its benefits and will increase the speed at which inaccuracies are identified, but it should be used alongside the knowledge of the artist assistant and the original scale-model.

DISCUSSION

To evaluate the utility of photogrammetry it is important to assess its strengths and weaknesses with the conservator in mind. From the results it is clear that for a conservator, photogrammetry offers the ability to create incredibly precise documentation that gives a clear representation of the artwork they are treating. It is also clear that the creation of a 3D model allows the conservator to conduct detailed analysis into its geometrical form. What is perhaps one of the biggest strengths of photogrammetry is that it is available to all who are willing to try. All conservators will have a good digital camera within their kit, the main piece of hardware needed for photogrammetry. The software used for this research, Agisoft Metashape, has a simple interface and a conservator would be able to work it if they spent the time

learning how to. Margins of error can come from the photographs that are taken, and whether the targets are placed accurately, which is something the conservator should keep in mind.

However, the technique can become expensive. Whilst an educational licence of Agisoft Metashape is 300 Euro, the professional licence is between 1,500 and 2,000 Euro. To run the software, a computer or laptop with a good processor and graphics card is needed. Although this particular software option can be expensive, there are plenty of open-source alternatives which enable the creation of 3D models such as Meshroom and Visual SfM. Yet, these open-source programmes typically require more than one piece of software to complete the entire process.

Another point to keep in mind is that the modelling process can be time consuming, with a higher-end 3D model taking on average between 3-9 hours to make from start to finish. The exact time depends on the size of the model being made and the specifications of the graphics card within the computer. To be specific, when creating the 3D model of the scale-model, manually editing the target points took 1 hour, converting the sparse point cloud into a dense point cloud took 2 hours, building the mesh took 3 hours and blending the textures took 0.5 hour. A large sculpture, such as *Jardin d'émmail* captured according to the resolution and accuracy requirements of this research, will take a few days to process on a computer with two processors. However, it is possible to run the modelling software and carry out other tasks whilst the model loads. It is also possible to stagger tasks and let the programme run overnight. Alternatively, it is possible to sacrifice the accuracy of the end result for processing speed. It is therefore important for the conservator to determine what level of accuracy is needed for the documentation or treatment being carried out.

As the technique could likely be outsourced to a company or professional specialising in photogrammetry, it is important to ask the following questions: do we value every aspect of the process the same? Is it difficult to communicate your wishes? Do they understand the point? By posing these questions, both parties have a clear understanding of what needs to be achieved. The 4D Research Lab explained that it might be possible for parts of a large sculpture to be missed in the photography process if the photographer is not properly briefed. As a result, it is important for the conservator to fully understand the process even if it is being outsourced. Both parties need to have a clear brief and be involved throughout to avoid any information loss from miscommunication.

CONCLUSION

Aside from mere documentation, photogrammetry can be used to inform conservation practice of painted outdoor sculpture by enabling a clear, geometrically accurate representation of the scale-model to be used as reference during the repainting process. This allows for a direct comparison between the scale-model and sculpture to be made, and any later mistakes to be immediately recognised and altered. Further analysis on

the photogrammetric data showed areas of deviation between the scale-model and the sculpture, which will allow appropriate planning to take place before repainting begins. The main strengths are the accuracy of depiction within digital 3D models and the fact that it's an incredible piece of documentation. The main weaknesses are the time and resources taken to produce the 3D digital model. It is up to the practising conservator to weigh up the benefits and drawbacks that such a technique will bring. Overall, this research has shown that photogrammetry can be a useful tool when repainting outdoor sculpture. The 3D model of the scale-model was successfully used to carry out the repainting of *Jardin d'émmail* between February – May 2020.

ACKNOWLEDGEMENTS

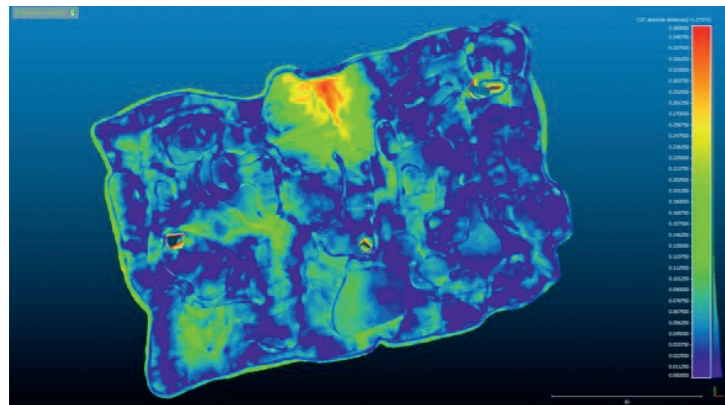
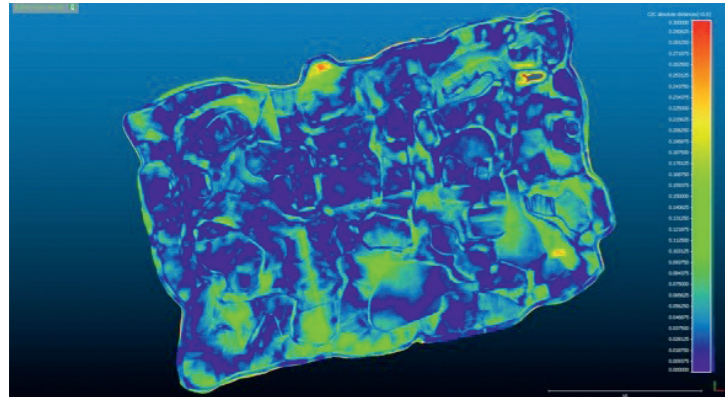
The main author would like to thank the following for the help and support with this research. To the 4D Research Lab at the University of Amsterdam for facilitating this research with their knowledge and expertise in image-based modelling; Jitte Waagen and Tijm Lanjouw. Equally, to the Kröller-Müller Museum for funding the analysis of *Jardin d'émmail*; Susanne Kensche, Tanja de Boer, Marcel van de Sande and Marjon Gemmeke. Finally, to the University of Amsterdam, particularly Sanneke Stigter for supervising this research, and equally to Evelyne Snijders, Katja van de Braak, Ellen Jansen, Professor Ella Hendriks, Professor Maarten van Bommel, Laura Wolfkamp, Claire Molgat Laurin and Hedwig Braam for their advice and support.

ENDNOTES

- (1) The conservation treatment of repainting the lines on the sculpture was completed in May 2020.
- (2) The architectural model was also referred to as a 'working model'.
- (3) Interview between Kröller-Müller Museum and Fondation Dubuffet. Participants: Richard Dhoedt, Sophie Webel, Susanne Kensche, Marcel van de Sande, Tanja de Boer, Marjon Gemmeke, Alice Watkins. Kröller-Müller Museum, Otterlo. 13 September 2018.
- (4) Interview between Susanne Kensche and Alice Watkins, Kröller-Müller Museum, Otterlo, 24 October 2018.
- (5) A tie-point is a feature that you can clearly identify in two or more images.
- (6) A point cloud is a set of data points in space representing a 3D shape or object.
- (7) Camera optimisation is when the camera's orientation is calibrated to improve accuracy and reduce the reprojection error.







Lecture 004 / Figure 6a, 6b

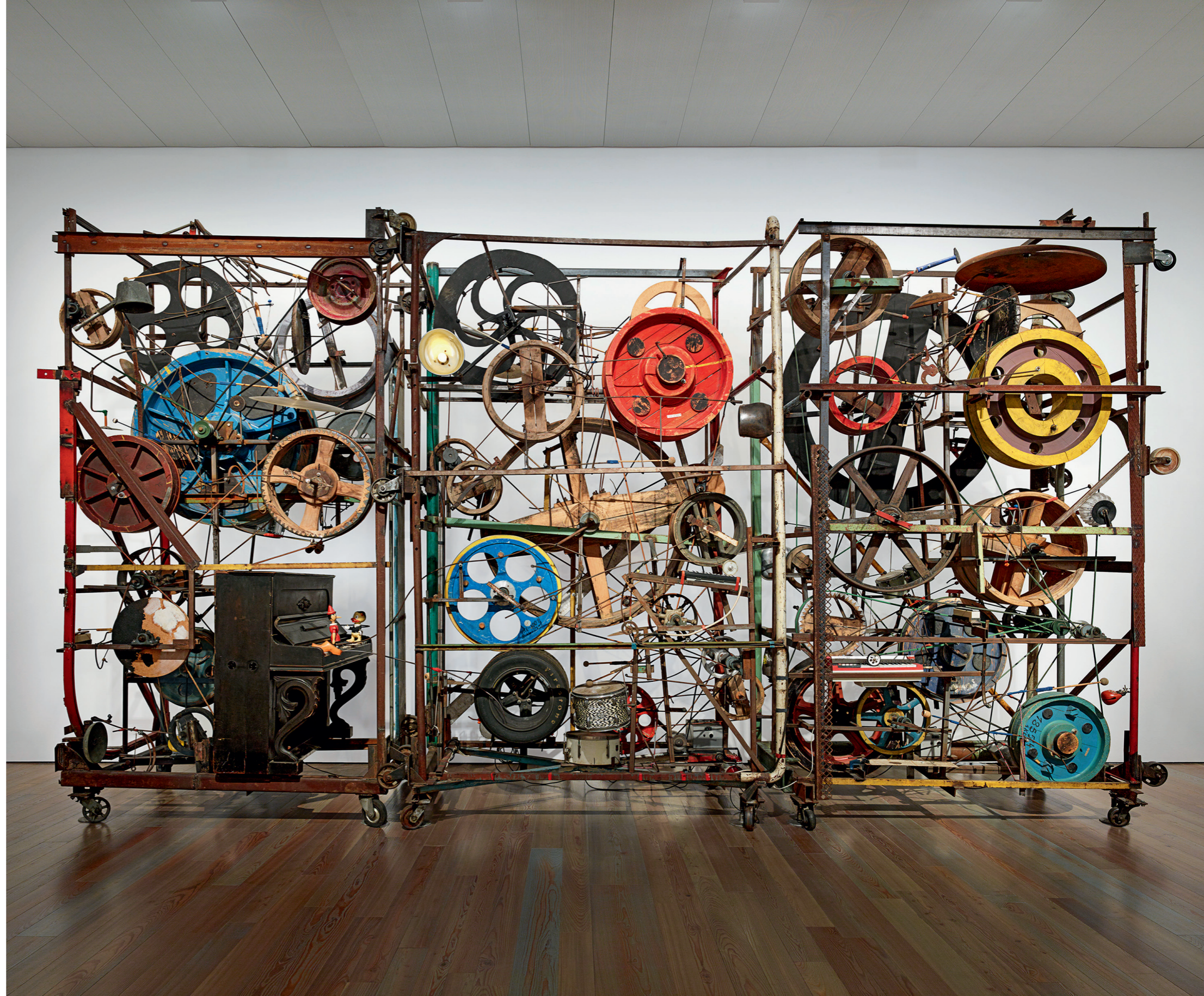
Fig. 6a.

Deviation analysis between *Jardin d'émail* and the architectural model using CloudCompare.

Credit: Tijm Lanjouw, November 2018.

Fig. 6b.

Deviation analysis between *Jardin d'émail* and the scale-model using CloudCompare.
Credit: Tijm Lanjouw, November 2018.



Lecture 005 / Figure 1

Jean Tinguely, *Méta-Harmonie II*, 1979,
Emanuel Hoffmann Foundation, 2019 (after restoration).
© VG Bild-Kunst, Bonn 2021

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LECTURE 003

SURFACE DEPOSITS ON FAUX LEATHER.

THE KEM WEBER AIR LINE CHAIR

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LECTURE 004

THE USE OF PHOTOGRAMMETRY IN THE CONSERVATION

OF PAINTED OUTDOOR SCULPTURE: ASSESSING

JEAN DUBUFFET’S JARDIN D’ÉMAIL

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LECTURE 005

TANGLING WITH ‘IRON SPAGHETTI’

SUPPLIERS

Epoxy resin Presto® and

epoxy resin Neukadur O-Paste SB:

Suter Kunststoffe AG, swiss-composite, Fraubrunnen, Switzerland

Epoxy resin Araldite® 2014-1

and polyurethane-resin Araldite® 2028-1:

Huntsman Corp., Texas, United-States

Acrylic resin Technovit® 4004:

Kulzer Technik, Wehrheim, Germany

Acrylic resin Paraloid™ B67; PVA-resin Mowilith® 50;

polyurethane-dispersion 61 PC; Iron mica (>63 µm);

graphite silver powder (< 40 µm);

black graphite powder (< 75 µm);

ivory black pigment and Arbocel® BW40 fibers:

Kremer Pigments Inc. Aichstetten, Germany

BLUFIXX® small repair, LED light-curing repair gel:

BLUFIXX® GmbH, Wesseling, Germany

Brass brazing solder no. 90:

Würth Group, Künzelsau, Germany

Powdered cellulose acetate and powdered rubber:

non-official supplier, supply by Empa,

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LECTURE 006

THE FUTURE OF RESPONSIVE SURFACES

IN THE LIQUID MODERNITY

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