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The Application of Reflectance Transformation Imaging (RTI) and Multispectral analysis (MSI) on Ancient Egyptian Coffin-lids at the Israel Museum, Jerusalem: a New Analytic Approach to Workshop Identification

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Abstract

This ongoing project (until September 2023) focuses on the study of two anthropoid coffin-lids donated to the Israel Museum in the early 1980s.
The first one, the coffin-lid of Djedmut, Chantress of Amun-Re (Inv. IMJ 82.2.341), dating from the late 21st Dynasty to the early part of the 22nd Dynasty.
The second one, the coffin-lid of Ptahhotep (Inv. IMJ 82.2.342), can be dated no earlier than the Late Period or even as late as the early Hellenistic Period.
In the present research, RTI is combined with multispectral imaging, valuable for the study of the pigments, to improve a detailed analysis and visualization of the artifacts' surface and highlight otherwise difficult-to-perceive features.
This analysis enhances faded decorations, reveals under-drawings, and aids in the identification of pigments, binders, reuses and other minute details of the production process, thus contributing to the identification of specific workshop profiles.

I. INTRODUCTION

Polychrome decorated coffins, especially those from the first millennium BCE, are among the most important artefacts from Ancient Egypt. The detailed study of decorated coffins enables one to obtain information on the society of the time, on individuals and their families, titles and institutions. Recent research also aims to reconstruct the production techniques and the social agency of the artists involved in the process.

The identification of distinctive thematic and stylistic motifs on contemporaneous coffins [1][2] suggests the presence of specific workshops that catered for particular sub-groups within Egyptian elites.

The present research aims to further characterize "workshop profiles" through the use of RTI (Reflectance Transformation Imaging) and multispectral analysis in order to better define the painting techniques, the materials used and the *modus operandi* of the ancient artists.

II. THE HISTORY OF SCHOLARSHIP

The discovery in the late 19th century of two caches containing hundreds of coffins dated to the early Third Intermediate Period, began a great adventure in Egyptology.

During the 20th century, the number of coffins increased greatly thanks to new discoveries, but it wasn't until the studies undertaken by K. Kitchen [3] on the Third Intermediate Period (TIP) that they received the recognition they deserved.

Initially, the coffins were studied with a special attention to the epigraphic aspects and the funerary texts. The importance of the material culture and its contribution

only began to be considered after A. Niwinski's pioneering work on the Theban coffins of the 21st dynasty [4], and J. Taylor's studies on the coffins of the 22nd to the 26th dynasty [5]. Further advancements were undertaken by K. Cooney and her focus on coffin reuse patterns as social responses to crisis, elaborating on the economic and political changes at the beginning of the TIP [6][7]. In recent years, a materiality-based approach encouraged the application of advanced analytic methods such as spectroscopy and microscopy aimed at identifying the artist's techniques and procedures, the materials and the pigments employed [8][9][10]. Different approaches were adopted by Egyptologists in studying the coffins but the identification of different workshops still remains a field in need of further exploration, due to the absence of a general comparative dataset of the various specimens spread over many museums all over the world. The Vatican Coffin Project, an international initiative, aims to change this situation by creating a unified database that will enable large scale cross-analysis between collections[1]. Two coffins at the Israel Museum are part of this joint effort.

III. The Egyptian Coffins at the Israel Museum

Two anthropoid wooden coffin lids were donated to the Israel Museum in the early 1980s by Wilma and Lawrence Tisch, purchasers of the Dayan collection. The coffin lid of Djedmut, Chantress of Amun-Re (Inv. IMJ 82.2.341, Fig.1), most likely originated from the Theban area. It represents a female deceased and is coated with a yellow base and decorated in polychrome.
The inscription is carelessly executed while the vignettes are expertly painted. Perhaps two different hands worked on the coffin.
Several traces which attest to the reuse of the coffin are present, as is quite a common phenomenon on the specimens of this type. The iconographic characteristics and the colouring technique allow to identify the coffin as Type V of the Yellow category, dating from the late 21st Dynasty to the early part of the 22nd Dynasty.
The coffin lid of Ptahhotep (Inv. IMJ 82.2.342, Fig. 2), entered the Egyptian collection of the Israel Museum only in 1982, after having been purchased by Arthur Sackler from the Anavian Gallery in New York in October 1975, and being auctioned previously at Christie's in March 1971 [11].
The lid represents a male deceased covered by a black background (possibly resin or bitumen) and decorated in yellow and red.
The scenes and vignettes are accompanied by short texts of recitations of the depicted deities.
The texts and images are not executed accurately and the face of the coffin seems to have been repainted, probably in modern time. The iconography suggests a dating not earlier than the Late Period or even as late as the early Hellenistic Period.

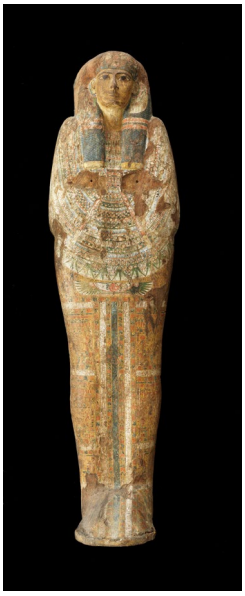

Fig. 1 - Coffin lid of Djedmut (Inv. IMJ 82.2.341)
Photo:© Israel Museum, by Eli Posener

Fig. 2 - Coffin lid of Ptahhotep (Inv. IMJ 82.2.342)
Photo:© Israel Museum, by Eli Posener

[1] The Vatican Coffin Project is a joint initiative involving some of the largest museums in the world and aimed at the study of the construction and painting techniques of *coffins* and at the identification of any "atelier".

IV. METHODOLOGY

A. Reflectance Transformation Imaging (RTI)

Reflection Transformation Imaging is a computational photographic technique invented by Tom Malzbender and Dan Gelb, researchers at Hewlett-Packard Labs. A landmark paper describing these first tools and methods was published in 2001 [12].
RTI captures the surface and colour of an object and allows it to be interactively re-illuminated from any direction; it also allows the mathematical enhancement of the shape of its surface and the attributes of its colour by means of particular tools based on mathematical algorithms. The enhancement functions of RTI reveal surface information that is not disclosed under direct empirical examination of the object (CHI 2002-2020) [13].
RTI images are created from multiple digital photos of a subject taken by a camera in a fixed position. For each photo, the light is projected from a different direction, thus determining different lighting. These multiple shots are brought together thanks to mathematical algorithms that form what is called "Polynomial Texture Mapping" (PTM).
Each RTI photo is therefore a two-dimensional image but, unlike a traditional image, it combines the reflectance factors of a 3D photo composing each pixel of the image, so that the RTI synthetic image reproduces the light reflecting on the subject.
When an RTI image is opened in RTI visualization software, each pixel is thus able to render the interactive virtual light of the software from any position chosen by the user. Therefore, changing the radius of incidence of light on the image reveals details of the surface of the object.
RTI has been applied here with the use of a manual flash (Highlight RTI or H-RTI): this technique can be used on small or large objects (up to 2 m in diameter) and can be adapted to a larger choice of surfaces or places (stelae, tomb reliefs, rock art etc.) and requires time to take the shots.
The equipment, based on a camera, a tripod and a portable flash, is easy to transport. During the image capture sequence, with the portable flash attached to a pole, you have to describe a virtual dome or a luminous hemisphere around the subject to be photographed. The quality of RTI images depends on the precise arrangement of the different lighting and its distribution.

V. RTI ON THE EGYPTIAN WOODEN COFFINS

RTI has been widely used for clarifying the fine surface details of tool marks, inscriptions and other surface details on archaeological artefacts.
In the field of Egyptology, it has only recently gained increased attention as a tool for the analysis of painted wooden surfaces.
RTI documentation is a tool to enhance the details of manufacturing and pigment application methods.
It is a natural way to document painting, since it overcomes the limitations of requiring raking light photography to reveal the decoration lines and method. RTI provides new and valuable information about the surface condition of the painted layers showing grainy surfaces of the pigments, marks relating to surface preparation and thin areas of texture, imperceptible to the naked eye or to other inspection techniques.
Using RTI on coffin surfaces and changing between different filters of RTI viewer program, the sequence of the painting layers becomes clearer. This sequence begins with the application of preparation layers on the wood, followed by marking-out lines, applying background colour, under-drawing, and filling-in of text and decoration with red, blue, and often green. The varnish is applied last on the coffin surface. The sequence of layers and colours can be determined due to differences in the thickness of the layers which are visible by RTI technique filters.

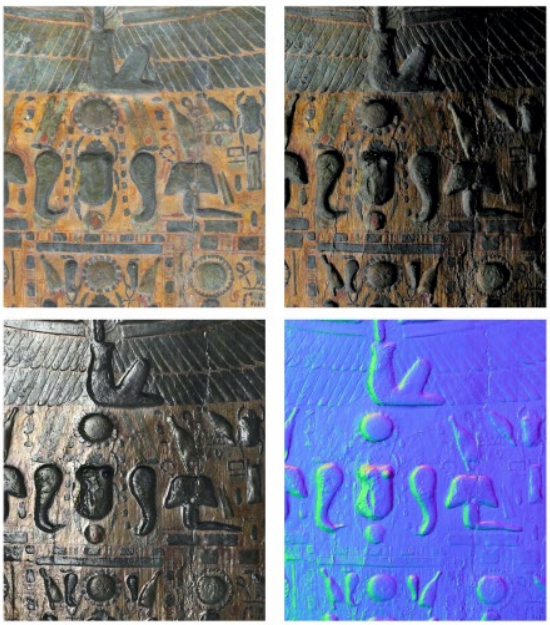

Fig. 3 - RTI Details with the use of different filters. A– Visible B- Diffuse gain C- Specular enhancement D- Normal visualization

These significantly successful applications demonstrate the great potential of RTI for painted wooden surfaces and in particular for the identification of workshops and artisan's hands, a venue which has so far been only marginally explored through RTI.
Within the present project it is also suggested that RTI in the infrared range can produce even better documentation with clear details and more information. Infrared light

provides more informative RTI images because some pigments, such as red ochre, become transparent. IR can help to show black lines clear in all the points so it's easy to detect the main lines used to frame the pigments. The standard IR photo already provides better documentation of the lines but without showing the thickness of lines or the stratigraphic structure of the pigments. IR increases the latter for improved detecting of brush direction of applying the preparation layer, traces, and evidences. RTI can also be combined with photogrammetry and *Multiband Imaging* (MBI) to improve a detailed study and visualization of an artifact's surface that highlights otherwise difficult-to-perceive features.
RTI is a non-invasive technique that eliminates all physical contact with the object. It makes possible to analyse the texture of the surface and to record details that are very difficult to grasp by the naked eye or by conventional photography.
It can help to look at brushstrokes in the case of painted coffins or details difficult to notice by naked eye, and it can be used in combination with multispectral imaging, valuable for the study of pigments.

VI. MAIN RESULTS

The field of coffin research, well explored abroad, has not yet been investigated in Israel. The new technologies, materials and methodologies involved will contribute to the establishment of a new field of research and in particular to the study of workshops.
The technologies applied provide information on the identification of the artist's hand, the brush strokes, the artisans' tools, but also the ancient natural environment by the study of the type of wood etc.
The data can be used to explore the role of craftsmen and artists in Ancient Egypt and their influence on the artistic choices of the coffin owner.
The employed methodology will not only illuminate hidden traits of the coffin production process but will also explore new protocols for data retrieval through multispectral analysis and RTI to contribute to the conservation process of these heritage objects.
The creation of digital images of these museum objects is also instrumental for the documentation, study and conservation of the coffins.
The application of RTI will provide new and valuable information about the surface condition of the painted layers showing the grainy surface of the pigments and the presence of many deformations and provides also more details about the manufacturing techniques (marks relating to surface preparation that was imperceptible to the naked eye or by other inspection techniques).
Finally, RTI enhances the morphology of some deteriorated materials, not easily visible, such as the micro-cracks in the varnish layer, but also parts treated by previous interventions as over-painting on the preparation layer or endorse the hypothesis of the reuse of the coffin.
Multispectral imaging (MSI) measures the reflectance and fluorescence properties of the different pigments using different wavelengths of light within the ultraviolet (UV), visible (VIS), and near-infrared (IR) spectrum.
Mainly, the following analysis have been carried out: ultraviolet florescence (UVF), ultraviolet reflected (UVR), visible-induced infrared luminescence (VIL) and infrared (IR) by a modified digital camera Fujifilm X-T30 used in different spectral ranges (from 350 to 1100nm). The MSI imaging has been combined with the XRF analysis of the pigments.
Ultraviolet (UV)-induced fluorescence is a widely exploited phenomenon in the analysis of polychrome. In particular, fluorescence spectroscopy is a non-invasive tool that can differentiate between materials with similar optical properties but different chemical compositions. Filters have been applied on the camera, combined with two UV 365 nm filtered lamps.
Ultraviolet reflected (UVR) interacts just with the very surface layer of paint is specific to the top most pigment and layers of paint underneath do not influence it. It reveals the white colour of gypsum which was used for the preparation layer before applying the colours. UV Band pass filter (325-380 nm) has been applied on the camera combined with two UV 365 nm filtered lamps.
Near-IR photography has been used with 850 nm filter and flash source. Some inks and pigments that are visually indistinguishable appear different under NIR.
Finally, the Visible Induced Luminescence (VIL) has shown an intensive response on Djedmut coffin lid, not only in the areas painted by Egyptian blue but also in other pigments, which testifies their mixture with the Egyptian blue.
VIL has been obtained with 850 nm filter and two battery operated red lamps 640 nm.

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