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3D/4D VISUALISATION FOR DOCUMENTING AND EDITING IMAGES OF PRE-ROMAN ITALY: THE ICAR DATABASE

1. Introduction

The ICAR database (Iconography and Archaeology for pre-Roman Italy) was created in 2000 under the direction of Natacha Lubtchansky[1]. This digital humanities documentation and research tool, specialising in the iconography of the various cultures of pre-Roman Italy, offers the online publication of several large corpora of figurative scenes produced by the Etruscan, Italic and Italiote peoples (http://icar.huma-num.fr/, ISSN 2491-2301). These cultures, which developed in Italy before the *imperium Romanum*, were particularly prolific in producing images to decorate their everyday, secular, and sacred objects. We chose to focus on works with figurative decoration, giving priority to published corpora. The aim of ICAR is to reflect current research by involving specialists of the corpora studied, without including any previously unpublished works, in order to respect the copyright of the institutions that own them. All works recorded in the ICAR database are therefore published, be they archaeological artefacts or graphic or photographic reproductions of the same. Our aim is also to ensure that the published corpora are exhaustive, so that users know which series of works they will find in the database and can carry out statistical analysis based on stable, reliable, and complete data.

2. The principles of the database

The ICAR database was designed to support a funded research programme on Image and Religion in pre-Roman Italy (Etruscan, Italic, Italiote), launched in 2000 as part of an Action Concertée Incitative Jeunes Chercheurs with the ESPRI team of the ArScAn research group, University of Paris Nanterre. Following development of the database's principles and architecture, a first corpus of Etruscan painted tombs was entered. This scientific programme

[1] This article has taken advantage of the discussions that took place at several seminars or conferences where the latest developments in the ICAR database were presented: a conference organized by F. De Angelis, New York Workshop of Etruscan Art, Columbia University, 29/04-01/05 2021; Festival de l'histoire de l'art, Fontainebleau, 05/06/2021; doctoral course organized by C. Rescigno, Storia e Trasmissione delle eredità culturali at the Università della Campania (Santa Maria Capua Vetere), 2/07/2021; CeTHiS Axis 3 workshop, Bases de données, de la conception à l'usage en ligne, 7/12/2022, U-Tours; International conference All'etrusca. La scoperta della cultura materiale e visiva nell'Europa premoderna e moderna, Roma, 23-25/02/2023, Swedish Institute of Classical Studies in Rome; École française de Rome; Séminaire d'ArcheoNum of ArScAn, 2/02/2023. We would like to thank Virginie Fromageot-Laniepce and Anne-Violaine Szabados for allowing us to publish the results of this work here.

took into account the archaeological context and the (mainly religious, but not exclusively) significance of the image. The aim was to make the image a historical document by displaying all of its components: its support (the archaeological object bearing the figurative decoration) with its various typological criteria; its place of production, with the date and the name of the artist or workshop, if assigned; its place of discovery; its place of conservation, with a history of the collections through which the work had passed to its current location. This information is systematically accompanied by the original bibliographical references, and if any piece of information proved contentious, other publications were also included. The database therefore provides an analytical bibliography of the recorded works, which we aim to update regularly.

3. Archaeological corpora recorded

Other scientific projects and collaborations with research institutions have enriched the database through the insertion of new corpora. Between 2004 and 2007, thanks to a second ACI, 'Iconography and Acculturation in Pre-Roman Italy', and the support of the Institut national d'Histoire de l'Art, the first Etruscan corpus was supplemented by the painted tombs of Campania and Apulia, the series of archaic reliefs from Chiusi and some black-figured vases. Specialists of these corpora (Rita Benassai, Luigi Finocchietti, Jean-René Jannot, Raffaella Bonaudo and Dimitri Paleothodoros) supervised the inputting of the data and obtained copyrights for the reproductions of the works. By 2023, the database will have five complete bodies of work available online, with a sixth coming soon:

– Etruscan painted tombs: 178 tombs, 571 scenes, 2,450 images.
– Campanian painted tombs: 44 tombs, 66 scenes, 82 images.
– Apulian painted tombs: 9 tombs, 16 scenes, 27 images.
– Archaic reliefs from Chiusi: 279 monuments, 571 scenes, 549 images.
– *Hydriae* from Cerveteri: 42 vases, 87 scenes, 182 images
– Etruscan black-figured vases, in progress.

4. Evolution of technical aspects and target audiences

The database was created using FileMaker Pro, with four record tables ('Supports', 'Scenes', 'Images' and 'Bibliography') and twelve relational tables (Fig. 1) containing the information mentioned above. Full corpora were made available online from 2002 onwards, using PHP with a MySQL database. IT management was provided on a volunteer basis by Sylvain Mottet, a computer scientist who, together with Natacha Lubtchansky, designed the architecture of the database and regularly took charge of putting it online and updating it.

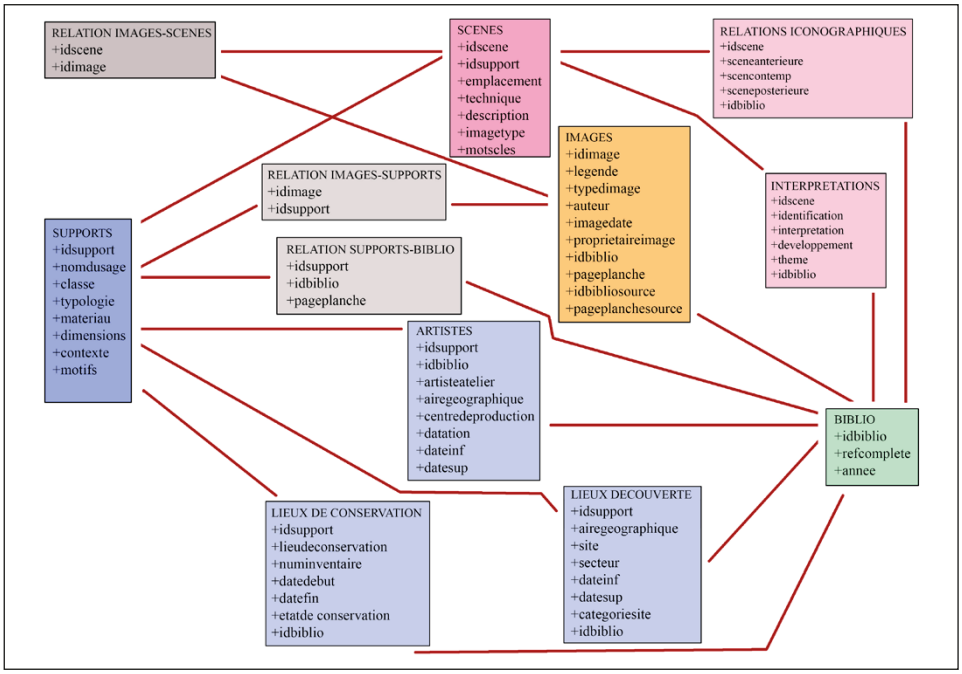

Fig. 1 – ICAR database architecture (Sylvain Mottet and François Ory).

In 2016, a number of developments emerged from a collaboration with the digital workshop (Atelier numérique) of the Maison des Sciences de l'Homme Val-de-Loire. Access to the data was facilitated using prioritization, improved ergonomics and a new user interface (Fig. 2). We also increased the number of search levels and answer modes. For example, in addition to the 'advanced search', aimed at researchers and users familiar with the database structure, we added a new 'guided search' for beginners, enabling them to find out about the different types of data offered by the database and the query processes for accessing them. As part of our commitment to making the site accessible to a wide range of users, we added English and Italian to the original French as display languages.

The interface, developed using the Symphony framework and PHP/MySQL, can be browsed on a computer or smartphone.

2021 also saw a major change: data can now be inputted in the database from an online interface, which had not been not possible until that point. This allows several people to work together on the ICAR database, while avoiding the creation of duplicates. This registration interface is also based on Symphony, with the EasyAdminBundle component.

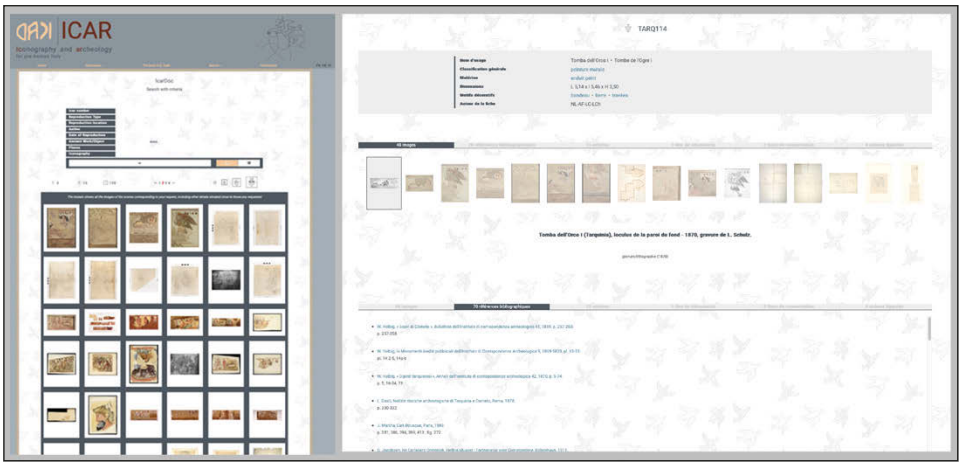

Fig. 2 – The ICAR user interface since 2016 (ICAR).

The software used is now being updated from Symphony 3.4 to 6.3 and PHP 8.2. Query options will also benefit from several changes based on user feedback.

The database is hosted by the Huma-Num infrastructure (CNRS).

5. The documentary turning point of 2015: ICAR and the history of reception

The archaeological orientation of the database has now been substantially enriched. The ICAR 'images' table contains both photographs and graphic reproductions, most of which date back to the 19th century, with several research programmes recently adding to the latter type: numerous drawings, watercolours, tracings and facsimiles have been made available in recent years. First and foremost is the inventory of the works of Augusto Guido Gatti, who worked as a draughtsman for the Tuscan Superintendency and produced paintings for the Galleria delle pitture etrusche in facsimile at the Museo Archeologico in Florence at the beginning of the 20th century. This work was undertaken by Susanna Sarti, Lucrezia Cuniglio (Soprintendenza Archeologia Belle Arti e Paesaggio per la città metropolitana di Firenze e le province di Pistoia e Prato) and Natacha Lubtchansky, and resulted in two publications[2]: a book featuring illustrations of a third of the works (Cuniglio,

[2] Institutional support was provided by the Soprintendenza Archeologia Belle Arti e Paesaggio per la città metropolitana di Firenze e le province di Pistoia e Prato; CeTHiS at the University of Tours; the École française de Rome; UMR 8546 AOROC; Labex Transfers and ANR CAECINA.

Lubtchansky, Sarti 2017) and an online edition of the entire collection. 325 new graphic documents were thereby added to the ICAR database's 'images' table, covering the corpus of Etruscan painted tombs and their various figurative scenes (Fenet, Lubtchansky 2020).

The same three researchers led a further programme at the École française de Rome between 2017 and 2021[3]. Entitled Facsimile. Graphic documentation and museums of Etruscan painting (Lubtchansky 2021; Cerchiai 2022; https://facsimile.hypotheses.org 2019-), it aimed to bring together the various collections of drawings and paintings reproducing Etruscan painted tombs. ICAR provided documentary and research support and now offers a complete interoperability portal for all sixteen collections studied, located in Europe and the United States. More than 2,000 archives were integrated for the 30 Etruscan painted tombs concerned, with the agreement of partner institutions.

While the earliest of these graphic documents reproducing Etruscan tomb paintings date back to the 18th century, most of them are from the 19th. The earlier series consists of watercolour drawings (plans, painted walls, perspective views), kept in the portfolios of the artists who visited these tombs, and occasionally published. The second set consists of reduced-scale watercolours in the tradition of the first series, as well as facsimiles and tracings reproducing tomb paintings at a 1:1 scale. These were used to create the museums of Etruscan painting that developed in Europe and in Boston for a century or so from the 1830s onwards, before they were overtaken by the practice of removing frescoes *in situ* and the use of photography. The usual practice, since its initiator Carlo Ruspi designed it for the Commissione Generale Consultiva di Belle Arti in the Vatican and the Instituto di Correspondenza Archeologica in Rome in the 19th century, had been to reproduce tomb paintings on tracing paper and then to make facsimiles on a 1:1 scale. Sets of watercolours with plans, sections and perspectives were also exhibited in museums, such as in Florence and in beer magnate Carl Jacobsen's Helbig Museum in Copenhagen (see lastly Moltesen 2019). The various pieces of this documentation have, in ideal cases, been preserved *in extenso*. They document the craftsmanship of the time, but also give today's archaeologists access to a state of the frescoes closer to that of the time of discovery before the fragile decoration was damaged by time and poor on-site conservation conditions.

The use of this new documentation considerably enriched the ICAR database: the tomb of Orcus from Tarquinia, for instance, which used to be the subject of 15 illustrations, including photographs and a few drawings,

[3] This École française de Rome programme was conducted in collaboration with the University of Tours, the ARPAMED sponsorship, the MSH Val de Loire and the Réseau national des MSH (funding for the associated project entitled ExSitu3D. From watercolours to 3D modelling of Etruscan painted tombs. See also the Hypotheses blog Facsimile (2019-): https://facsimile.hypotheses.org.

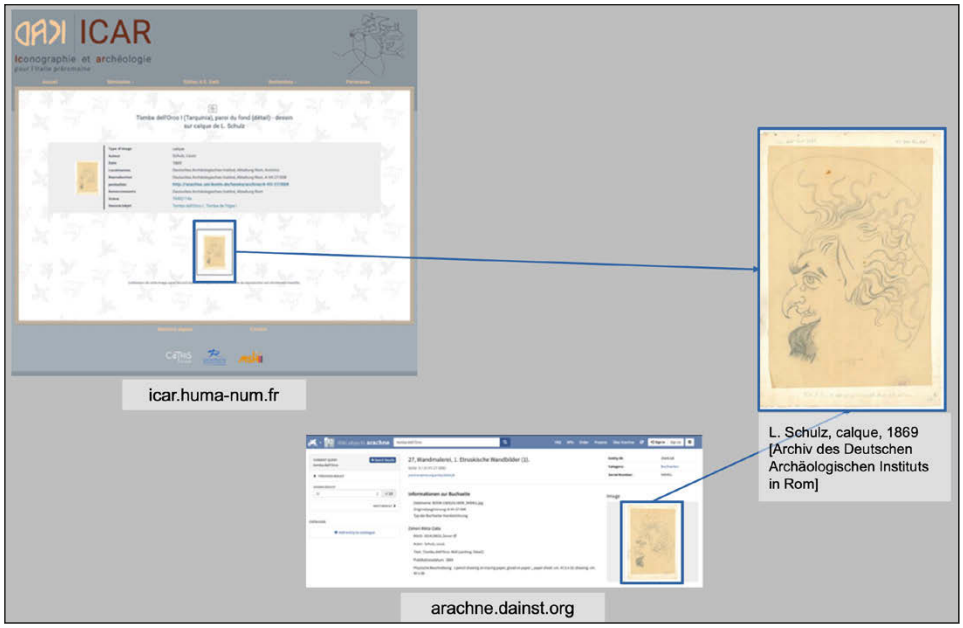

Fig. 3 – The head of the demon *Charun* from the tomb of Orcus in Tarquinia, based on a drawing on tracing paper by L. Schulz (Deutsches Archäologisches Institut in Rome).

was supplemented with 113 new graphic representations. The scientific project, which was able to establish a research network, sought a principle of interoperability: each record devoted to a graphic document is linked to the holding institution's website using a permalink. Some institutions allowed us to display the image in good resolution on ICAR, while in other cases ICAR only displays a miniature thumbnail of the work (Fig. 3).

6. ICAR 4D: graphic archives in diachrony, in 3D tombs

The next step was to improve the visual cross-referencing of graphic archives and archaeological heritage. The development of an exploratory tool for two Tarquinia tombs (Fig. 4) – the tomb of the Bigas (BIGHE 4D) and the tomb of Orcus (ORCUS 4D) – was conditioned by several scientific objectives.

These two tombs were chosen for several reasons. From an archaeological and artistic point of view, both are masterpieces of their chronological period: the Archaic period for the tomb of the Bigas, painted in the Severe style (480 BC) and the Classical period for the tomb of Orcus, the oldest chamber of which dates from 390 BC and the most recent painting from 350 BC. Each of these tombs adopts the architectural and decorative typology of its period,

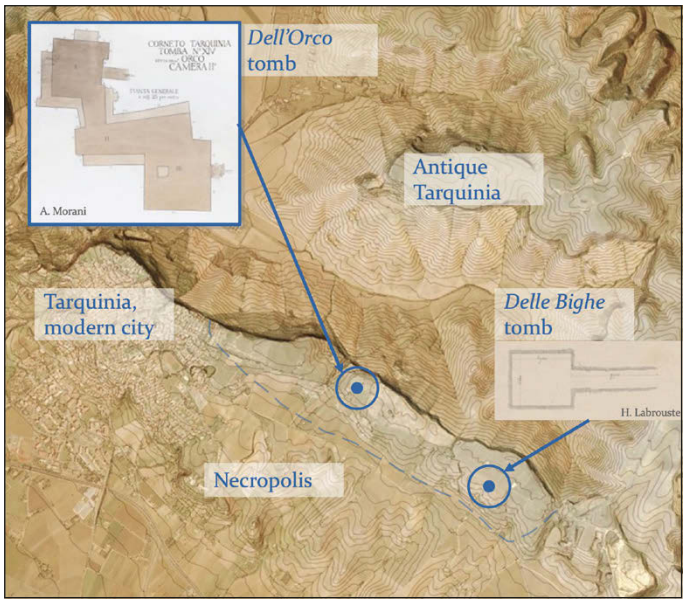

Fig. 4 – Original location of the two tombs (Alban-Brice Pimpaud).

while being distinguished by an original interpretation of these standards and exceptional artistic skill in their application. The tomb of the Bigas features a typical late Archaic decoration, with its aristocratic *symposion* on the back wall of the cubic chamber and dances on the side walls. Its originality is confirmed by the small frieze running above the megalography, which shows a succession of equestrian, gymnastic and theatrical games taking place before spectators seated in stands. The tomb of Orcus follows the Classical decorative programme, with the oldest room evoking Hades, where several couples are taking part in a *symposion*, through the use of black mist and the inclusion of infernal genies. The later section displays a topography of the afterlife, with the heroes and divinities encountered by Ulysses and Aeneas during their respective catabases, completed by a tableware dresser attended by servants, and the representation of the blinding of Polyphemus by Ulysses.

Both tombs have suffered the cruel ravages of time. Discovered in 1827, the tomb of the Bigas immediately became famous as the work of a Greek painter, recognized by its stylistic proximity to Attic vases, and therefore one of the rare examples of large-scale Greek painting (*megalographia*) to have been preserved. Travellers were however reporting its deterioration as early as 1831 (Lubtchansky 2011, 196; forthcoming), and in the post-war period, its worsening condition due to environmental humidity and the development

of conservation techniques led to its frescoes being removed and installed in the Museum of Tarquinia in 1949 (Cecchini 2012, 72). The tomb of Orcus was discovered in 1868 beneath the modern cemetery of Tarquinia. It had already been subsiding before its discovery, and its stability remains under threat to this day: as such, it has never been opened to the public. The two painted tombs therefore present a special conservation situation, with the first's decoration no longer in the necropolis, and the second only accessible with official authorisation. As a result, they had never been digitised.

The exceptional quality of these two tombs attracted visitors and scholars from the moment they were discovered (Lubtchansky forthcoming; Lubtchansky, Labregère forthcoming). Both monuments quickly became must-sees for visitors, and copies of them were drawn by architects and painters for a variety of reasons: to be published, to set up museums of Etruscan painting and, in the case of France, for educational purposes (training at the Beaux-Arts) (Lubtchansky 2017). From the time of its discovery until the end of the twentieth century, the tomb of the Bigas was the subject of 203 graphic works, including 118 tracings[4], 11 painted facsimiles, 43 watercolours or coloured drawings and 31 lithographs, executed between 1827 and 1989 by at least twelve different authors[5] and now held in seventeen institutions or private collections[6]. As regards the tomb of Orcus, the 124 graphic works representing it include 53 tracings, 20 painted facsimiles, 43 watercolours and 8 lithographs, executed between 1869 and 1993, by five workshops or individual painters[7] and currently kept in seven institutions or private collections[8].

[4] The tracing collection at the Svenska Institutet in Rome contains 106 items, divided into three different sets. This substantial number is due to the highly detailed layout of the different scenes of the tomb.

[5] The architects and painters were Joseph Thürmer (1827-29); Otto Magnus von Stackelberg (1827-29); Henri Labrouste (1829); Félix Duban (1829); Anonyme Doucet (circa 1830); Benjamin Schlick (1832); Charles Questel (1832); Carlo Ruspi (1835-1838); Alessandro Morani et al (1900-1910); Leo D'Alessandri (or Elio D'Alessandris) (1911-12); Jutta Weber and Mickael Sohn (1989).

[6] The conservation institutions are Bibliothèque nationale de France (Paris); École nationale supérieure des Beaux-Arts (Paris) Bibliothèque nationale de France (Paris); École nationale supérieure des Beaux-Arts (Paris); Institut national d'Histoire de l'Art (Paris); Deutsches Archäologisches Institut-Rom; Museo gregoriano etrusco (Vaticano); Staatliche Graphische Sammlung (Munich); British Museum. Department of Prints and Drawings (London); Svenska Institutet i Rom; Ny Carlsberg Glyptotek (Copenhagen); Museum of Fine Arts (Boston); Museo delle Antichità Etrusche e Italiche, Sapienza Università di Roma; C. Weber-Lehmann Archives (Bochum).

[7] These workshops and painters were Alessandro Morani *et al*. (1900-1910); Augusto Guido Gatti (1910-16); Leo D'Alessandri (or Elio D'Alessandris) (1911-12); Jutta Weber et Mickael Sohn (1988-1993).

[8] The Conservation institutions are Deutsches Archäologisches Institut-Rom; Svenska Institutet Rome); Ny Carlsberg Glyptotek (Copenhagen); Museum of Fine Arts (Boston); Museo delle Antichità Etrusche e Italiche, Sapienza Università di Roma; Museo Archeologico Nazionale di Firenze; Archives C. Weber-Lehmann Archives (Bochum).

7. The scientific objectives of 4D exploration

The first objective of this exploratory tool is to allow the three-dimensional visualisation of all archival documents held in various international institutions for both tombs (respectively 203 and 124 items), rather than as a mosaic of images (Fig. 5), as on the ICAR database. The modern reproductions are therefore inserted into both tombs' architectural volume,

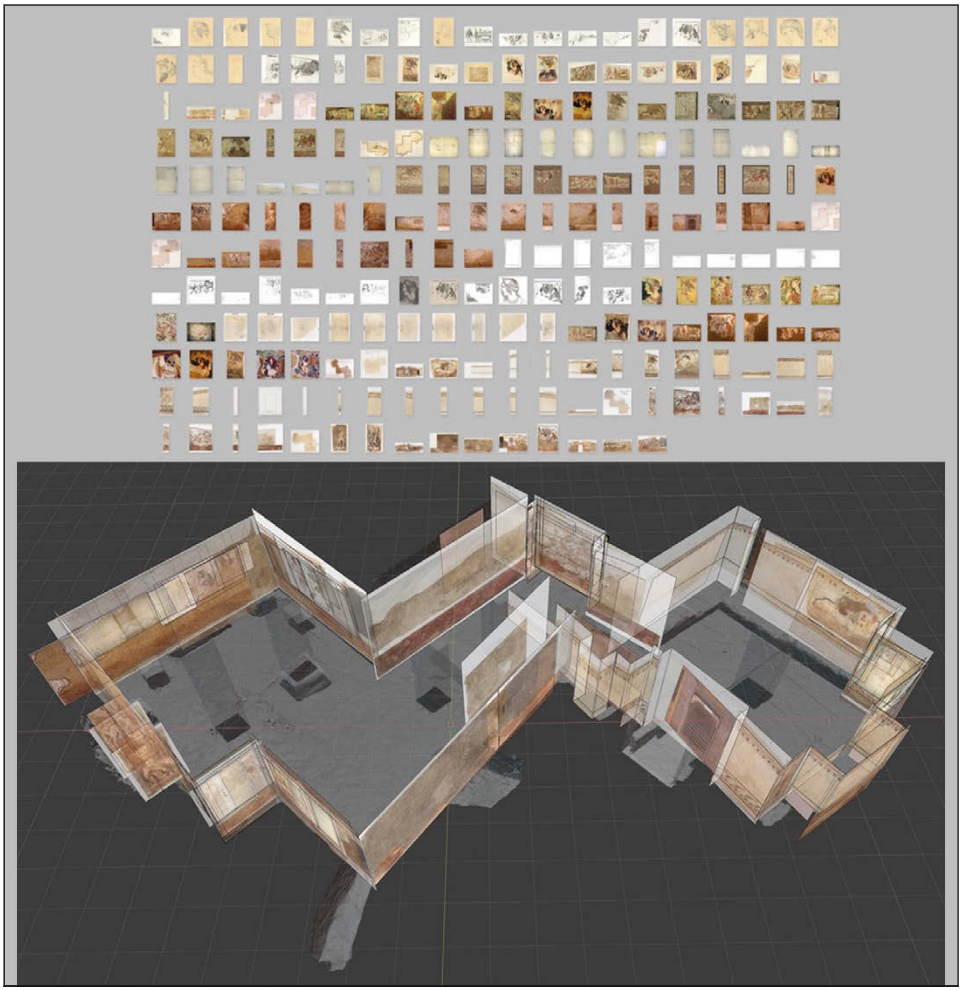

Fig. 5 – The mosaic of archival documents for the tomb of Orcus of Tarquinia and insertion of the same in the 3D modelling (Alban-Brice Pimpaud).

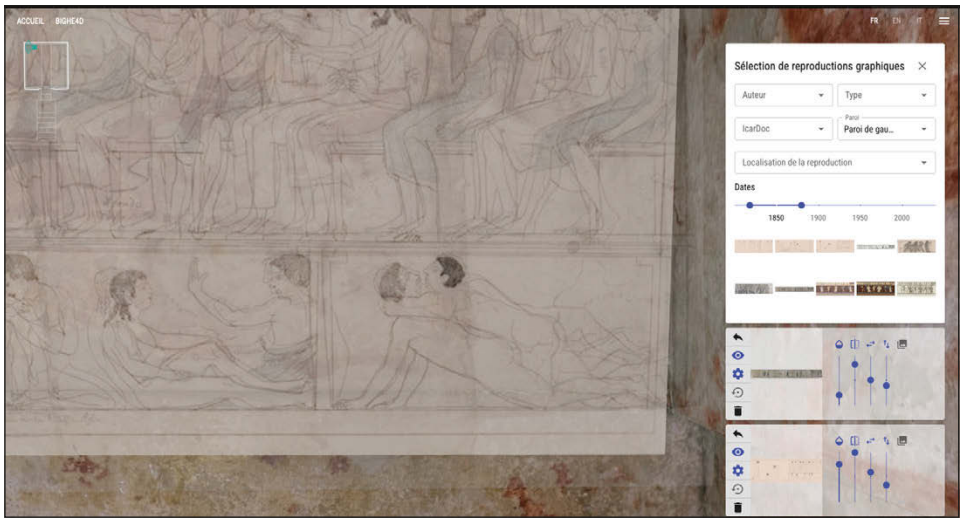

Fig. 6 – The BIGHE 4D interface, detail of the spectator stand on the left wall, with the athletic or erotic scene (ICAR).

reconstituted in 3D, to demonstrate the spatial organisation of the archival images. Since the object of the study was the images themselves, high resolution visual data was required to allow work on their figurative detail. 3D modelling allowed us to get as close as possible to the frescoes in both tombs to appreciate their details, and the graphic archives are presented with the same precision.

As the model in Fig. 5 shows, the archives are projected superimposed onto the walls of the tomb. The oldest is placed closest to the wall with the others on top in chronological order, creating a chronological palimpsest and adding a fourth temporal dimension to the three spatial ones.

The user interface provides the main information on the graphic documents: author, place of conservation, material, reference in the ICAR database and dating (which can be accessed using a timeline). Buttons can be used to show or remove selected archives, or to display all the items from a given collection onto the entire tomb. The transparency of an archival item can be adjusted and the user can also move it a few centimetres in three dimensions (in depth/ vertically/ horizontally) to better compare the modern document with the ancient fresco, with the aim of clarifying the current gaps in the monument and completing the ancient iconographic text. These tools can also be used to compare two archives. Comparisons can help to decide which variant is the most relevant, in cases where the current state of the fresco is fragmentary.

For example (Fig. 6) in this example from BIGHE 4D (http://icar.huma-num.fr/4D/Bighe4D), the badly damaged detail of the fresco depicting the spectator stand on the left wall has been superimposed with two graphic works. This detail, which has now largely disappeared, depicts two men lying under the seated spectators, in an action that can be interpreted in two different ways: Otto Magnus von Stackelberg, who discovered the tomb in 1827 and published his reduced-scale drawings in 1829, reconstructed a wrestling scene, with the man on the right lying with his back to his opponent (ICAR TARQ23-100: http://icar.huma-num.fr/web/fr/icardoc/image/3343). Carlo Ruspi, who reproduced the fresco in 1835, saw it as an erotic scene between both men, the one on the left lying on top of the other. In the facsimile for the Gregorian Etruscan Museum in the Vatican[9] (ICAR TARQ23-34: http://icar.huma-num.fr/web/fr/icardoc/image/1201), this detail was removed, whereas in the facsimiles he produced for the Pall Mall exhibition in London and for the Alte Pinakothek in Munich, he chose the erotic version of his preparatory tracing.

For navigation, the viewer can move around the room using the mouse or with a shortcut on a mini map of the tomb in the top left-hand corner. Given the dimensions of the room, the field of view can be changed in the settings and, in the case of the tomb of Orcus, modern structures such as the 19th-century pillars can be removed to clear the visual perspective.

This interface brings to light the semantic link between the scene depicted on the archive and its arrangement in the tomb. We consider these graphic documents not simply in terms of their own materiality, but in coherence with the archaeological space. We can thereby firmly combine the point of view of the archaeologist, who studies the composition and significance of a funerary decoration's iconographic programme, and that of the historian of the reception of antiquity, who can provide valuable information on the state of the frescoes as they were at the time of their discovery. It is worth pointing out that, at the time they were produced, facsimiles were displayed on museum walls simply as paintings, with no semantic link with the architecture of the tomb they came from[10]. The approach adopted in our programme therefore moves away from this decorative or aesthetic point of view.

Thirdly, the interface contributes to the history of the techniques used to produce the graphic documentation of the modern era. By comparing

[9] This is its publication in Canina 1846-1851, vol. II, fig. 85,2.

[10] See Lubtchansky 2017, where I analyse the variations over time in the way the architecture of the tomb is taken into account in reproductions of Etruscan frescoes. The Pall Mall exhibition in London in 1837 and the cork models are two examples that seek to insert the copies – natural scale in the first case and reduced scale in the second – into a spatial reconstruction of the tomb.

archives with each other, thanks to their projection on the walls and their horizontal, vertical or depth adjustment, we can check that a particular tracing was used to produce a particular facsimile; we can appreciate the changes between a tracing, a 1:1-scale facsimile, and a reduced-scale watercolour; we can also check whether painters copied one another. We know, for instance, that Carlo Ruspi's early drawings were studied by other workshops at the end of the 19th century, and that Henri Labrouste's drawings were copied by numerous student architects who did not necessarily travel to Tarquinia, which was difficult to access at the time (Lubtchansky 2017). This interface may therefore help to resolve the question of whether painters and architects were really working *in situ*, or whether their copies were based on earlier works or publications.

8. Dissemination works around ICAR 4D

A tutorial (http://icar.huma-num.fr/4D/videos/tutoriel.mp4) is available on the ICAR 4D home page (http://icar.huma-num.fr/4D/) to familiarise the public with this multi-faceted interface. The programme is also presented in a 52-minute documentary film (*Couleurs étrusques: Regards croisés sur la peinture étrusque*), broadcast on Canal-U (https://www.canal-u.tv/video/msh_val_de_loire/couleurs_etrusques.55457) and the ARPAMED channel, complemented by a teaser focusing on BIGHE 4D and ORCO 4D (available on the ICAR 4D home page: http://icar.huma-num.fr/4D/videos/film.mp4). All the work related to this programme is presented on the Facsimile Hypotheses blog (https://facsimile.hypotheses.org).

ORCO 4D (http://icar.huma-num.fr/4D/Orco4D) is also supplemented by an interface for students and the general public, entitled ORCO 3D: http://icar.huma-num.fr/4D/Orco. The development of this digital publication aims to reflect the originality and artistic excellence of this painted tomb, as well as the many scientific and heritage studies that have been carried out on it.

The ORCO 3D interface provides access to this monument in 3D, as well as the latest proposals on its chronology, the significance of its iconographic programme and the history of its reception since its discovery.

Twenty stations were selected for this online guided tour (http://icar.huma-num.fr/4D/Orco/3D), but users can also move around the 3D model as they please, moving as close to or as far away from the walls as they wish. A general explanation of the various scenes is provided, and a series of pins offer insights into the details of the frescoes. In addition, a glossary of over 130 terms, relating to Etruscan archaeology and art as well as the history of the discovery of the painted tombs, explains the meaning of the most important concepts. All the information is presented in three languages: French,

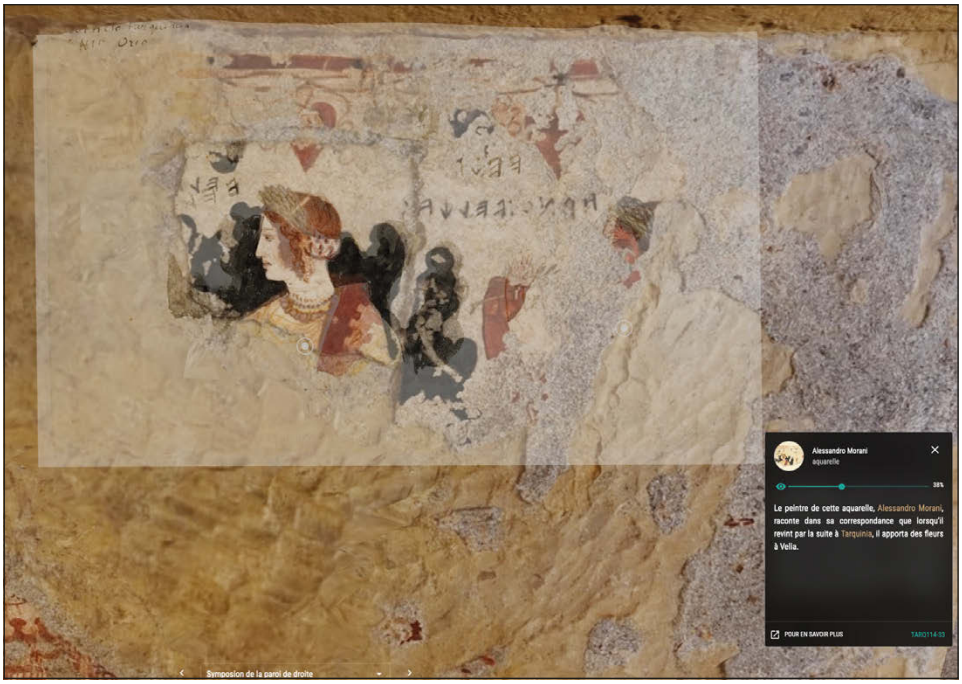

Fig. 7 – The ORCO 3D interface. Presentation of the right wall of chamber 1 with the watercolour by A. Morani (ICAR).

English, and Italian. Two modern graphic reproductions were chosen for each of the twenty scenes depicted, to show their contribution to understanding the iconographic programme and the history of the monument (Fig. 7). Links to the ICAR database are also provided for each ancient or modern work mentioned for further information.

The guided tour through the virtual space of the tomb is completed by four special sections.

The first allows the user to appreciate the historical and geographical context of the tomb within the ancient Mediterranean and the Etruscan city of Tarquinia: http://icar.huma-num.fr/4D/Orco/geographie .

The second (http://icar.huma-num.fr/4D/Orco/chronologie) provides a visual reconstruction, with commentary, of the evolution of the tomb's architecture between 400 BC, when the first burial chamber was dug, and the end of the 19th century, when the structure was reinforced following the discovery of the tomb. It summarizes the research work carried out on the much-debated issue of dating the various ancient constructions and destructions of the monument.

In conjunction with the Facsimile programme, a third section maps the various international collections that hold copies of graphic reproductions of the frescoes in the tomb of Orcus. A history of each collection is presented by the collection specialists: http://icar.huma-num.fr/4D/Orco/collections.

Finally, there is a focus (http://icar.huma-num.fr/4D/Orco/beaufort) on the role played by the French colonel Philippe Léonce de Beaufort in the discovery of the tomb, and on his archaeological collection, now held at the Musée George Sand et de la Vallée Noire in La Châtre, Berry. It includes several ancient artefacts that could well have come from the tomb, given their dating and place of production.

9. Technical workflows

To conclude this presentation, the following summarizes some processes involved in the making of the interactive applications described above, from 3D digitization to online publication.

9.1 *Digitization of the tombs*

Given the various locations and conservation conditions of the tombs, the 3D digitization had to meet two technical objectives:

– Ensure the geometric accuracy of the survey, and therefore offer a high degree of precision in the restitution of volumes, in order to obtain ground truth models,
– Record the smallest details of the painted decoration to facilitate the 3D registration of the graphic archives, and therefore obtain the best resolution as well as a suitable chromatic depth.

Accurate surveys were produced with a reasonable number of stations during a lasergrammetry campaign[11]: 19 for the tomb of Orcus and 2 for the tomb of the Bigas. While the quality of the on-board imagery was enough to document the volumetry and the local variations of the walls surfaces, it was unable to reproduce the finesse and colours of the paintings: the average resolution obtained by laser scanning would have enabled life-size prints to be made at 15 dpi, whereas we are commonly accustomed to appreciating prints of photographs or drawing at 300 dpi or higher. Moreover, the 360° views required to colorize the point clouds suffered from vastly differing lighting conditions (Fig. 8). Resolution, which depends on the number of stations and their distance from the subject, was another limiting factor.

[11] The FARO Focus S 150 scanner, operated by Jean-Philippe Corbellini (MSH Val-de-Loire), achieved an accuracy of about 1 mm and an average resolution of 1.6 mm.

Fig. 8 – Colorized point cloud of the tomb of Orcus, with under/over exposure and shadows. Closeup of a region with a 1.6 mm resolution (Jean-Philippe Corbellini and Alban-Brice Pimpaud).

Fig. 9 – 3D digitization processes, from left to right – point cloud, shaded photogrammetric model, textures. Tomb of Orcus (Alban-Brice Pimpaud).

As such, photogrammetry was the natural choice to achieve the resolution and chromatic homogeneity needed to properly document the paintings. RAW images shot at an average distance of 1 m from the wall and from various angles enabled us to increase both texture resolution and overall chromatic coherence, all while collecting much more 3D details and avoiding cast shadows as much as possible.

The tomb of Orcus was eventually documented by more than 3,600 photos and the tomb of the Bigas by about 920, using light photographic equipment consisting of battery-powered LED lighting and hybrid cameras equipped with lenses suitable for low light conditions[12].

The photographic collections of both tombs were then processed in photogrammetry software (RealityCapture, https://www.capturingreality.com) and matched to the laser-generated point clouds. This fully exploited the advantages of both digitizing methods, i.e. the accuracy of the laser and the information density of the photograph (Fig. 9).

The results of photogrammetric calculations were 3D models with very dense meshes and a large number of textures. This considerable quantity of data, which can only be handled on a powerful computer, had to be optimized for the archive registration process, as well as for the front-end web applications designed to run on average machines.

9.2 *Processing of the 3D textured models*

The raw 3D models were first exported as OBJ files for processing in Instant Meshes (https://github.com/wjakob/instant-meshes), which reduced the tomb of Orcus from 400 million to 6.8 million faces, and the tomb of the Bigas from 18 million to 1 million, while outputting more manageable models made of retopologized quadrangular faces instead of unordered triangular ones.

To improve the 3D experience, while editing the models we segmented the wall surfaces according to their nature and condition of preservation. In the case of the tomb of Orcus, we distinguished between collapsed walls and ceilings, carved architectural elements, preparatory surfaces, painted walls, floors, modern elements, and chronological phases. For the tomb of the Bigas, segmentation was performed according to the position of the paintings in relation to the architectural structure of the tomb (panel, ceiling, central beam, pediment, etc.).

Segmentation of the models enabled us to enhance the quantity and resolution of textures (Fig. 10), since collapsed ceilings, modern elements

[12] SONY Alpha 6000 cameras and SIGMA 16 mm and 30 mm lenses at f1.4; the resulting images are 6000 × 4000 pixels.

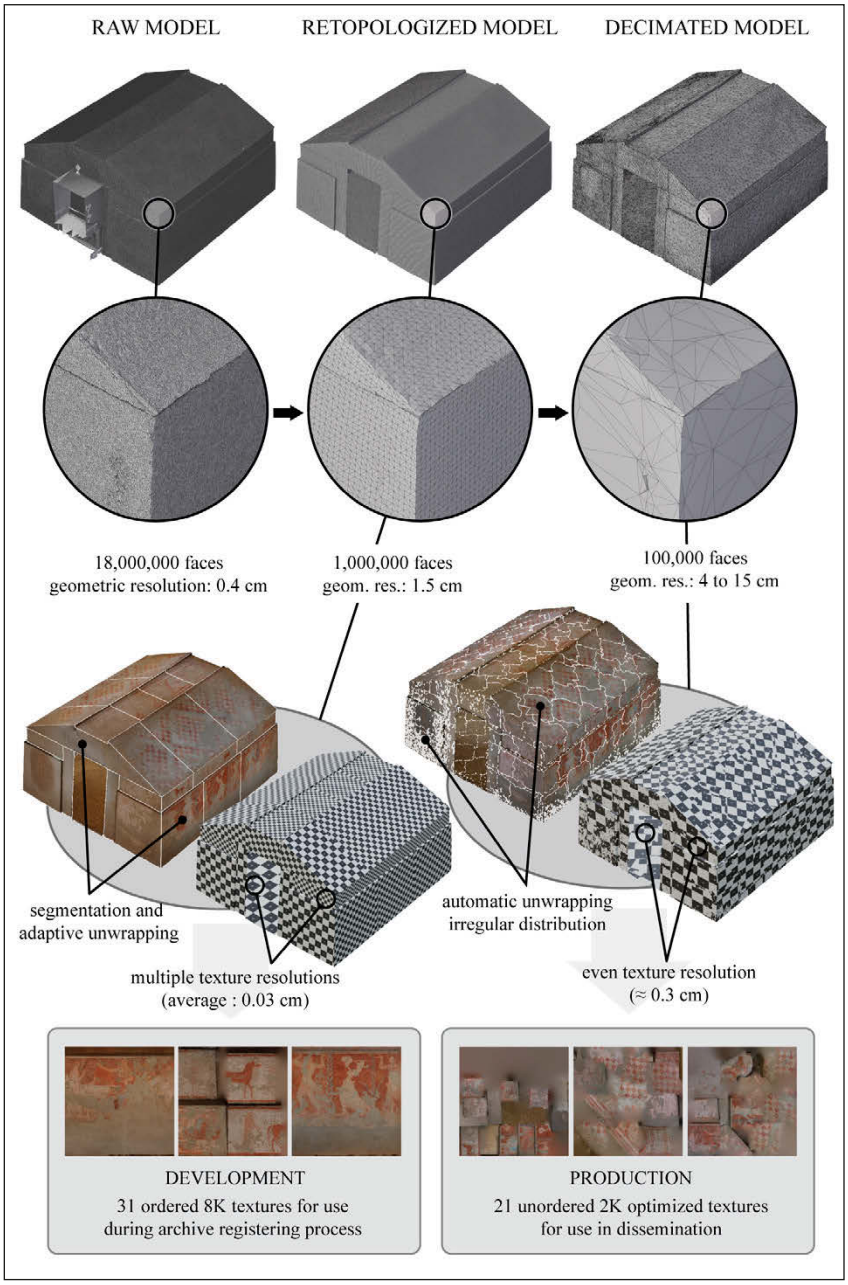

Fig. 10 – Segmentation, decimation, and texturing processes for the tomb of the Bigas (Alban-Brice Pimpaud).

and floors need not be as finely documented as painted plaster or carved decorations. In the case of the tomb of the Bigas, we were able to focus on some very subtle detail, especially where our graphical documentation is very fine, whereas other areas without decoration nor documentation did not require much texture allocation. Despite this, the final twenty 8192×8192 pixel textures required for the tomb of Orcus and the thirty or so for the tomb of the Bigas remain a relatively large number.

9.3 *Registering 2D archives onto 3D models*

Once the textured models were made available in Blender, we had to prepare the archival graphic files. Documents were reframed as closely as possible to reduce file and texture size; composite plates were broken down into individual files as needed. The files were then duplicated and spread to directories according to their resolutions using a robust and unambiguous naming pattern.

The archive was then inserted into Blender as an 'empty' 3D image object. It was scaled if the information was available, and positioned as close as possible to the wall, trying to align to it, using translation and scaling rotation tools, and adjusting transparency levels to get as close as possible to the motif. Archives, grouped by collection, could then be displayed or hidden in Blender during this input phase. In the end, geometric parameters describing these registered 'archive' 3D objects were then added to the data extracted from the ICAR database using a Python script, so that they can be recreated on demand in the application. All external data describing these 3D archives was recorded in a JSON format file, which can be easily interpreted by the software platform used to build the application.

9.4 *Front-end application specifications*

Given the objectives and the variety of documents we needed to manipulate within the applications, we chose the open-source framework React (https://react.dev), which offers the possibility to integrate a large number of Javascript libraries to the source code and to compile it in the form of a responsive website. The Material UI library, with its numerous predefined components, was adopted for building the user interface (https://mui.com); 3D integration relies on the Three.JS library (https://threejs.org) and its various abstractions in the React ecosystem (https://github.com/pmndrs/react-three-fiber); 3D models were decimated and exported as GLTF Files; the interactive scalable maps (from worldwide to the Tarquinia area) are based on the Leaflet library (https://leafletjs.com). Plans for navigating in the tombs were produced in SVG, while all text, glossaries and the interface were encoded in trilingual JSON files (English, Italian, French).

The entire source code is stored on a GitLab repository hosted on Huma-Num's research infrastructure (https://gitlab.huma-num.fr/apimpaud/orco4d), and the application itself can be consulted on the platform's web service (http://icar.huma-num.fr/4D).

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ABSTRACT

It has been over twenty years since the ICAR database of figurative scenes from pre-Roman Italy (Etruscan, Italic, Italiote) was first made available online to researchers, students and the general public (http://icar.huma-num.fr/, 2002-, ISSN 2491-2301). The database is a tool for documentation and research into ancient iconography, bringing together the major corpora of images from pre-Roman Italy and providing the main information (archaeological, historical, stylistic, discovery, conservation, bibliographical) relating to them. Since 2000, ICAR has been developing its activities in association with various iconographic research programmes. Over the last ten years the database has also taken into account the modern documentation of the ancient artefacts and offers a data interoperability portal bringing together all the international collections preserving modern reproductions of Etruscan painting. Within this framework, we developed an exploratory tool (ICAR 4D) to combine high-definition 3D digitizations of two Etruscan painted tombs (the tombs of the Bigas and of Orcus in Tarquinia) with all the drawings and paintings produced over more than a century since the discovery of the two monuments. This tool uses cross-browser and open-source libraries to digitally expose and allow 3-D real-time online examination of both tombs' models and their rich graphical documentation.