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DIGIT-KEY: an aid towards uniform 2D+ and 3D digitisation techniques within natural history collections

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Abstract. Natural History institutes hold an immense number of specimens and artefacts. For years these collections were not accessible online, remaining inaccessible to researchers from far away and hidden from the general public. Large digitisation projects and cross-institutional agreements aim to bring their collections into the digital era, such as the SYNTHESYS+ project and the Distributed System of Scientific Collections (DiSSCo) Research Infrastructure. As specimens are 3D physical objects with different characteristics many techniques are available to 3D digitise them. For inexperienced users this can be quite overwhelming. Which techniques are already well tested in other institutions and are suitable for a specific specimen or collection? To investigate this, we have set up a dichotomous identification key for digitisation techniques: DIGIT-KEY, (https://digit.naturalheritage.be/digit-key). For each technique, examples used in SYNTHESYS+ Institutions are visualised and training manuals provided. All information can be easily updated and representatives can be contacted if necessary to request more information about a certain technique. This key can be helpful to achieve comparable results across institutions when digitising collections on demand in future DiSSCo research initiatives coordinated through the European Loans and Visits System (ELViS) for Virtual and Transnational Access.

Keywords. Digitisation, natural history collections, Digital twin, virtual collections, 3D.

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Introduction

It is estimated that globally around 1.2–2.1 billion specimens are kept within Natural History collections (Ariño 2010). These collections shed light on the biodiversity of the past and are indispensable in current biological and environmental research. In the last decades, many initiatives have started to open up these collections to make them accessible to a wider audience and researchers across the globe. So far, these projects are organised on a continental scale. The Integrated Digitized Biocollections (iDigBio, https://www.idigbio.org/) Project is responsible for fostering digitization and use of these data and natural history collections in the US and worldwide. For the Commonwealth, CSIRO exists, which is the Commonwealth Scientific and Industrial Research Organisation, leading initiatives in and around Australia (https://www.csiro.au/).

In Europe, natural history institutes are working towards the Distributed System of Scientific Collections (DiSSCo, https://www.dissco.eu/) which is a new Research Infrastructure (RI) for Natural Science Collections. It aims to improve physical and digital access to natural science collections by helping to enable and support industrial-scale digitisation. To quote the DiSSCo website: “The DiSSCo RI aims to create a new business model for a European collection that digitally unifies all European natural science assets under common access, curation, policies and practices that ensure that all the data is easily Findable, Accessible, Interoperable and Reusable (FAIR principles) (Wilkinson *et al.* 2016)."

The road towards DiSSCo has been prepared by several projects. The most recent are SYNTHESYS+ (Synthesys of Systematic Resources, https://www.synthesys.info/; Smith *et al.* 2019) and DiSSCo Prepare (https://www.dissco.eu/dissco-ppp/). These projects are supported by the Consortium of European Taxonomic Facilities (CETAF, https://cetaf.org/), founded by natural history institutes within Europe to promote scientific research and enhance access to European natural history collections. It aims to represent the interests of its member institutes, increase its members' visibility, and to be an unified voice for natural history collections and collection-based research in Europe.

The completed DiSSCo projects have aimed to ensure that all partners within DiSSCo are meeting the same uniform standards for providing access to the collections. The DiSSCo initiative will help scientists tackle large and complex research questions using the physical specimens and their digital twins across institutional borders with greater ease than before.

The natural science collections community continues to evolve and mature within the landscape of the European Research Area. The many facets and research activities associated with collections are fostering the development of tools, new skills, and competencies to facilitate access to the complex area of specimen conservation, specimen management, and associated knowledge transfer as a valuable heritage for understanding biodiversity. Digitisation of collections benefits the community in many ways. It has a direct influence on liberating data for researchers (Hedrick *et al.* 2020) as well as having economic value (Popov *et al.* 2021).

Digitisation of collections

Relatively recently, consulting multiple collections was cumbersome as catalogues were often available only on paper. If already digitised, they often lacked crucial information, which is only visible on the labels of the specimens. The first digitisation initiatives focused on digitising these metadata, setting up digital catalogues with as much information as possible. Adding images of labels, written catalogues, or field notes to these repositories was a logical step to fill the gap of missing data. Through citizen science projects many of the data on these labels are transcribed so they can be used in research projects (Hill *et al.* 2012; DIGIVOL 2024; DoeDat 2024; Notes From Nature 2024). But it is also important that the physical specimen itself is digitised in the best way possible. As most museums lack sufficient staff and taxonomic experts are limited across these institutes, the identity of many specimens can't be verified during the digitisation process. Detailed information about the physical specimen in 3D or 2D+ makes it possible for specialists in other research infrastructures to correctly identify the digitised natural history specimen, which is a crucial step in valorising the data (Greeff *et al.* 2022). In addition, these media objects and annotations on them make it possible to better understand and share widely where further expertise is needed in the cases where identification by image is not possible or needs confirmation.

SYNTHESYS Projects

During SYNTHESYS+ and previous projects, including SYNTHESYS3, a lot of effort has been put into looking at the needs of the participating institutes and their community to digitise the collections. To ensure digitisation techniques are standardised, many workflows and best practices have been created and shared among institutes. These efforts paved the road towards the DiSSCo initiative, which not only aims to join collections but also to share knowledge. Although still in its preparatory phase, through the DiSSCo Knowledge Base (https://know.dissco.eu/) it will be possible to retrieve reports, papers, handbooks, etc. written about managing and digitising natural history collections. Once fully operational these should also include the numerous efforts and publications of global wide initiatives. For now, these are deliverables or products of the several DiSSCo-linked projects such as SYNTHESYS+. The

Knowledge Base ensures this information is not lost when these projects come to an end. Besides the information accessible through the DiSSCo Knowledge Base, a web interface combining all the digitisation guides has been set up (https://dissco.github.io/). The services accessible through the DiSSCo website are still developing and more information will be added.

In the DiSSCo Digitisation Guides, multiple guidelines are proposed as digitisation best practises and workflows. The majority of events that can and do happen in a digitization process are covered (e.g., from selecting specimens, setting up the physical specimens for imaging, processing the images, and returning specimens to the collections). A simplified version of such a pathway is represented in Fig. 1. The part 'Digitise Specimen', represented in bold, is a part that is very specimen and/or research dependent.

When looking into detail in these presented workflows and digitisation best practices it is clear that, at the moment, the focus is on digitisation of 2D information or in producing simple 2D images. Several papers have been written on how to create mass digitisation setups to retrieve label data as quickly as possible, sometimes even without touching the labels or removing them from a pinned insects (Dupont & Price 2019; Allan *et al.* 2019; Dupont *et al.* 2020). Specimens in natural history collections may have undergone different preservation techniques and the way their data/labels are stored with the physical specimen may vary from collection to collection. These methods are sufficient for reproducing data visible on labels, herbarium sheets or written on microscope slides. They are often not sufficient for providing the most information from the physical specimen, i.e., the specimen itself.

These published guidelines in manuscripts and papers are also primarily static, they don't evolve through time, while techniques do change at a rapid rate. Digitisation technology is developing very fast and information produced within these guidelines is in danger of becoming outdated quickly. Detailed

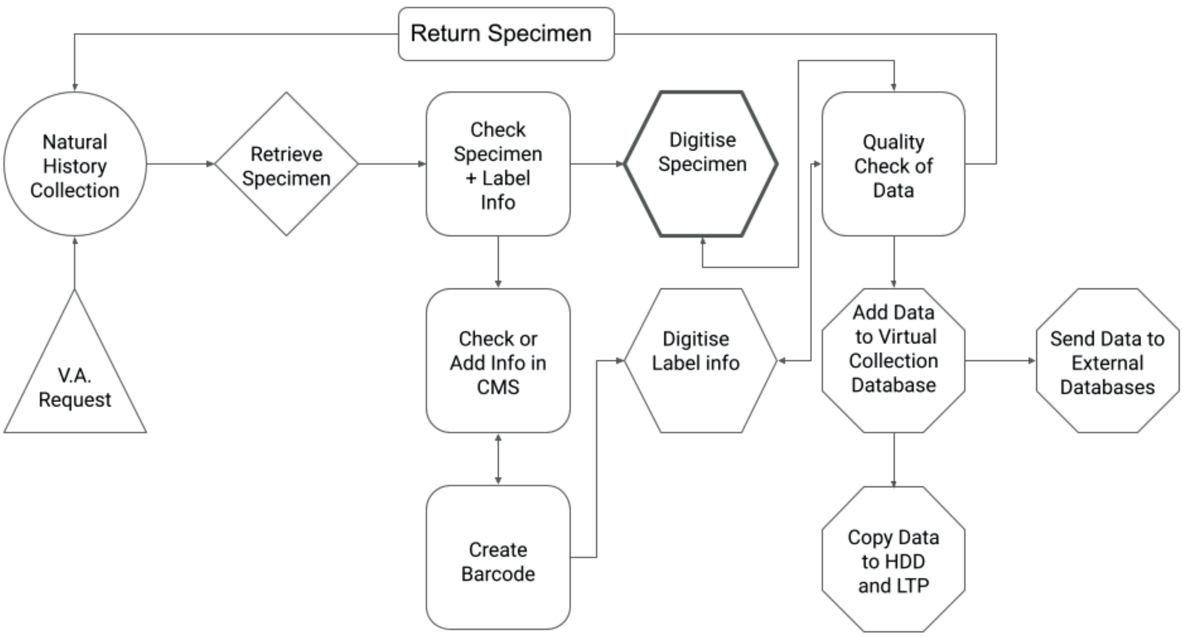

Fig. 1. Overview of a simplified standard digitisation workflow following a Virtual Access request. Abbreviations: V.A. = Virtual Access; CMS = Collection Management System; HDD = Hard Disk Drive; LTP = LongTerm Preservation platform.

guidelines can provide too much information to process when one doesn't have an exact idea which technique should be used to tackle the digitisation demand.

Specimens in a natural history collection are of such diversity, going from microscopic to building size, from shiny iridescent polychromatic objects to matt unicolored specimens, that a plethora of techniques are needed or can be used to digitise them in 2D+ or 3D. Previously, within the SYNTHESYS3 (https://synthesys3.myspecies.info/) framework, two best practice handbooks on 2D+ and 3D digitisation have been written discussing the possibilities of digitisation in Natural History techniques (Keklikoglou *et al.* 2019; Brecko & Mathys 2020). Every technique has its own outcome and possibilities for future research (Brecko & Mathys 2020).

DiSSCo intends to liberate the specimen information and provide virtual access to this data through their Digital Specimen Repository (https://sandbox.dissco.tech/). Using the collections of the SYNTHESYS+ and DiSSCo institutes, large digitization efforts to address research needs will be managed using the European Loans and Visits System (ELViS). Through this system, large research initiatives can request access to physical and virtual specimen data across institutional borders. The uniform way that data, whether it is 2D, 2D+ or 3D, are presented is the key element in such requests.

Liberating Collections

The SYNTHESYS+ programme has already launched, being tested in two Virtual Access calls, where researchers requested digital information for specimens. Some of these projects required transcription data and 2D information to answer their research questions. Other requests focused on the 3D representation of specimens. It is clear that liberating collections enhances research (Drew 2017). Whilst some research questions require destructive sampling of specimens, some 3D digitisation techniques can provide the information, reducing the need for additional sampling.

During the Joint Research Activities (JRA) in SYNTHESYS+ it became clear that several institutes use similar techniques to digitise specimens on a daily basis (Table 1). Ideally, the digitisation of a specimen captures as much of the physical information as possible in the digital twin. The selection of the appropriate digitisation method for a specimen is dependent on the Digitisation on Demand (DoD), i.e., what is needed to answer a research question. However, most institutions have similar collections or similar goals in terms of the final digitised product, be it 2D, 2D+ or 3D.

Material and methods

Digitisation of a collection

To digitise a collection, a technology has to be chosen, deciding whether a commercial package or an open-source solution is the best option. Workflows published today may not be helpful in the near future, given the rapid technological developments. It is, therefore, necessary to come up with a solution that will be more stable through time, is easy to use, and gives information about a specific digitisation question and provide the list of existing digitisation equipment among the DiSSCo community. This network system needs to include versioning and robust metadata standards.

For some pipelines, similar or identical setups are used by several partners (e.g., Artec scanners). In this case, it is possible to share the experience and the protocols. For others, like Micro-Computed Tomography (microCT) or microphotography, different instruments were selected by the partners. It is still possible to share general strategies, sample preparation protocols or post-treatment tools as analysis workflow but the precise digitisation workflow is often focused on the use of a specific instrument.

Table 1. Overview of the digitisation setups used by each partner. The setups are placed in several technique groups. The setups maked with an asterix (*) have an online workflow present in the DIGIT-KEY.

	Institution						
	RBINS	**RMCA**	**HCMR**	**MNHN**	**RBGK**	**NHMW**	**MNCN-CSIC**
Centralised platform	shared platform		micro CT	micro CT		micro CT	micro CT
2D Techniques							
2D photography large objects*	X	X		X	X	X	
A3 scanner with backlight				X			
A3 scanner with top view	X					X	
A0 scanner	X						
2D+ Techniques							
Focus Stacking*	X	X		X		X	
Multispectral Megavision*	X						
Multiband flashguns + filters*		X					
X-Ray VisiX		X				X	
SEM/ESEM*	X	X		X		X	X
Microscope slides*	X	X		X	X	X	
Confocal laser microscopy*							X
3D microscope* Keyence VR 5000 Hirox RH-2000 Leica DCM8	X			X		X	X
Optical extended microscopy		X					X
Portable multiband light dome	(X)			X			
Microanalyzer						X	
3D Surface scan: SfM							
SfM Agisoft metashape*	X	X		X	X		X
Multiband SfM Agisoft metashape*	X	X					
3D focus stacking SfM (manual)*	X	X					
3D focus stacking SfM (automatic)*	X				X		X
3D Surface Scan: Handheld structured light scanner							
Artec Space Spider*	X	X				X	X
Artec Spider MHT*							X
Artec Eva*	X						X
Artec Leo						X	
Mantis F6 SR*		X					
Shining 3D Einstar		X					
Shining 3D Einscan H2	X						
3D Surface scan: Structured light scanner on tripod							
HDI Advance R3X*	X			X			
Mechscan*	X			X			
Breuckman Stereo*				X			
3D Surface scan: Laser scanner							
Range 7				X			
FARO Edge ARM*				X			
3D Volume / Internal structures: micro-CT							
SkyScan 1172*			X				
Baker Hughes v | tome | x L 240-180*				X			
Nikon CT SCAN XH 160*							X
RX Solutions EasyTOM150*	X						
RX Solutions EasyTom 150 S				X			
XRE (TESCAN) UniTOM*	X						
YXLON FF35 CT*						X	

The organisation of the digitisation pipelines is different within institutions. In some partners, all digitisation instruments are managed by a central digitisation unit at the institution level. The access and the prioritisation are also defined centrally which facilitates the integration in a wider structure like DiSSCo. RBINS and RMCA which collaborate together in the digitisation of the collections have the largest panel of digitisation instruments among the SYNTHESYS+ JRA partners, covering most of the techniques used. On the other hand, HCMR has only one digitisation instrument (microCT) but developed a state-of-the-art workflow. Other institutions have a decentralised structure and each scientific department is responsible for their digitisation instruments. In some cases the very expensive instruments, like microCT scanners, are nevertheless managed by a central structure. This situation creates different scenarios of workflow and requires standardisation to be included and shared in a wider infrastructure like DiSSCo.

Results

DIGIT-KEY

To ensure that information on digitisation strategies, pathways and equipment is kept up to date, and to help potential users to decide the appropriate digitisation method for their needs, a dynamic digitisation key was created: the DIGIT-KEY (https://digit.naturalheritage.be/digit-key). The DIGIT-KEY is the result of the work done within JRA2 of SYNTHESYS3, Task 7.2. Digitisation on Demand workflows

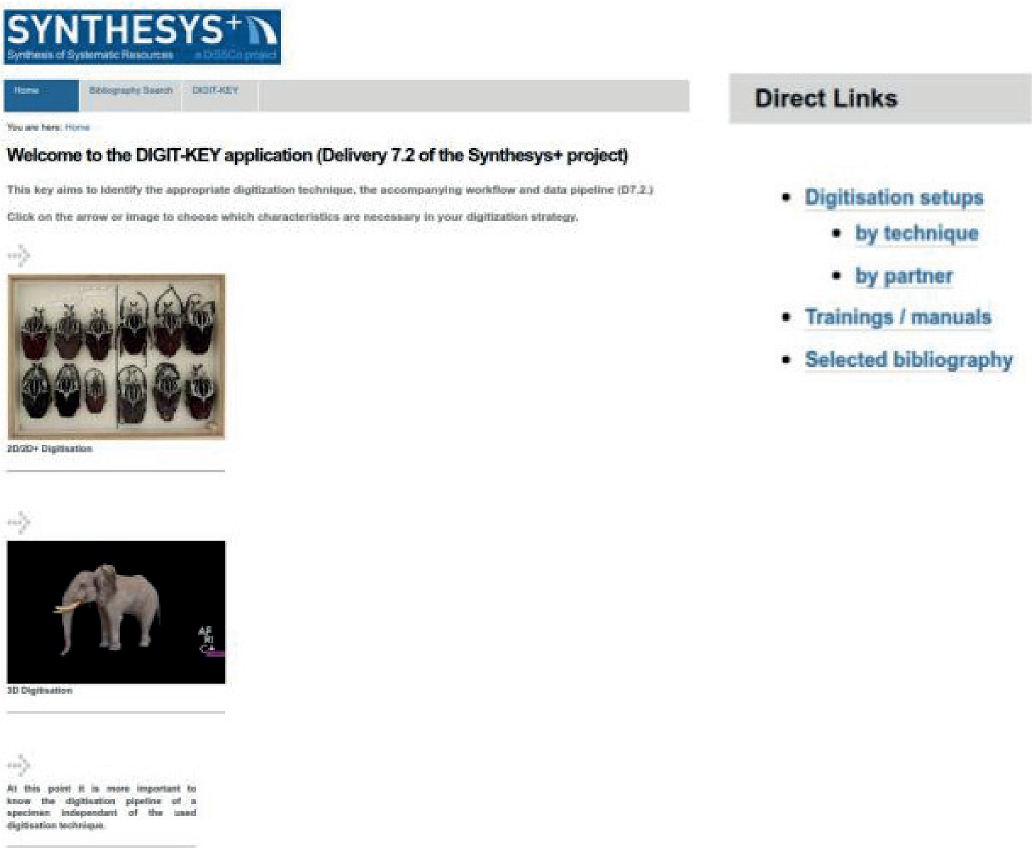

Fig. 2. Home page of the DIGIT-KEY (https://digit.naturalheritage.be/digit-key). Using the left panel, the user can select the 2D/2D+ digitisation, 3D digitisation module or directly go to the available workflows. Using the right panel, it is possible to explore the available techniques, partner information, training manuals and relative bibliography.

in SYNTHESYS+ and WP8.1: Specialisation plan of DiSSCo Prepare / Transition. The DIGIT-KEY (Fig. 2) is used to identify the process in the 'Digitise Specimen' step in Fig. 1. The DIGIT-KEY will help to standardise digitisation techniques and produced outcomes. Using similar techniques across institutes ensures that digitised data are comparable and can be used within the same Virtual Access demands, in the future through the ELViS platform of DiSSCo. The reason standardisation is important is the large differences within techniques. A good example is SfM photogrammetry where one can already create a model with a handful of images. Most scanning techniques foresee the option to fill gaps to make models watertight so it looks complete, while in essence data is created, which probably is not correct. Also, within handheld scanners there are models that are at an entry level and have a lower accuracy than a more high-end model, while they do rely on the same technique to capture data.

The DIGIT-KEY architecture

The digitisation key is a set of dichotomous choices that allows the user to select the best digitisation technique and to explore the setups already in use in the DiSSCo community. The key is based on the various main questions that are asked by a digitisation expert when someone wants a specimen to be digitised. What is it that needs to be digitised? What are the specimens properties (size, colour, preservation method used, ...)? What is it that needs to be seen on the digitised files? Does only the external view has to be recorded or are internal characters also important? Has the representation of the specimen to be done in 2D, 2D+ or 3D? What is the level of detail that is needed?

DIGIT-KEY is made in Plone CMS as this has multiple benefits. Plone is an Open source content management system. Even if Plone is not the most used CMS compared to Drupal or Wordpress, it is recognized as the most stable and secure one (cvedetails.com). RBINS has been using Plone CMS since 2005 and continues to develop new tools related to the collections and the online publication of data using ver. 4.3 and Plone ver. 6.0 (which is the most recent version).

Plone includes an integrated Object-Oriented Database allowing users to define with GUI new content types and fields (dexterity). All objects created in the Plone database use the Dublin Core standard. The objects can also be tagged with keywords and related to other objects of the database. A bibliographic product manages references with import / export in Bibtex or RIS format. All objects in Plone are fully indexed (data and Dublin Core metadata). This allows a full search using a simple interface of combining several conditions at the level of each indexed field. Finally, the faceted search add-on allows users to easily create dynamic search interfaces which automatically update if new content is added or edited.

One of the advantages of Plone CMS is that it is possible to create public objects in private folders or private objects in public folders. This is not a common feature in CMS which often manage the access rights at the level of the space and not of the document / object. This feature allows to mix public and private information in the same structure helping the organisation of the information. The precise financial data related to a specific setup are often under a privacy policy. The public objects make it possible to display the information without authentication requiring robots (e.g., Google) to index the content but the private state information is only available using the authorised role of an authenticated user.

We defined several branches in the workflows on the base of existing setups and workflows among the DiSSCo SYNTHESYS+ T7.2 partners. Simple 2D setups like digital photography of single specimens of medium size or imaging the label information are not included. This is already presented in the DiSSCo Digitisation Guides (https://www.dissco.eu/digitisation-guide/).

The digitisation techniques, workflows and guides presented in the DIGIT-KEY are designed to recommend the best technique for digitising the specimen itself, rather than only information on the label, as was often the case with earlier workflows. Both together are, of course, indispensable to create best digitisation practice. A specimen without a label has less value to the scientific community just as a label without a specimen to confirm the taxonomic information on it.

The key is divided in two main parts: 2D/2D+ and 3D workflows respectively. The first one is related to the 2D/2D+ approaches (Fig. 3).

The 2D+ approaches are related to SEM / ESEM, multispectral illumination, extended focus and virtual illumination. The final result is always a 2D image.

2D/2D+ workflow

- The choices made in the first branches will decide whether to use electronic microscopy, multispectral light or visible light.
- The second branch in the visible spectrum gives the option between the digitisation of complete boxes / drawers and the digitisation of a single specimen / object.
- The fourth branch is related to the size of the specimen.
    - The category of specimens with a size smaller than 2 mm returns to the optical microscopy.
    - The specimens / objects with a size between 2 mm and 25 cm can follow two workflows using extended focus or virtual illumination.
    - The specimens / objects with a size bigger than 25 cm can follow two workflows depending on their size and weight.

As an example, the pathway would be as follows for the digitisation of a collection of small, pinned insects for which the images need to be useful for taxonomic research, i.e., with crisp details, all in-focus, and accurate colour information:

1. The collection or specimen has to be digitised in:
    ○ 2D/2D+
2. The light source to be used during the digitisation

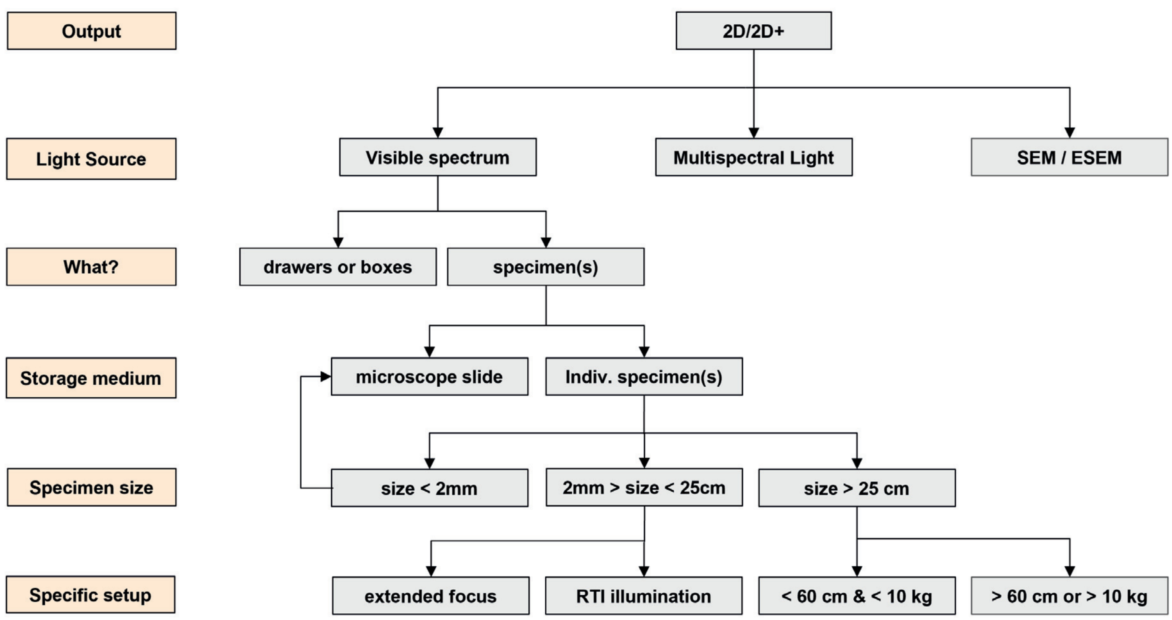

Fig. 3. The hierarchical structure of the 2D/2D+ part of the DIGIT-KEY.

   ○ visible spectrum
3. What do you intend to scan?
   ○ individual specimens
4. The single specimens are
   ○ not mounted on a microscope slide
5. The single specimens are =
   ○ 2 mm > specimen size < 25 cm
     and technique needed:
   ○ extended focus
6. Proposed technique: low cost focus stacking (RBINS / RMCA)

The second part is related to the 3D/3D+ approaches (Fig. 4):
the final result is a 3D model (shape with or without texture) or a set of 2D images allowing the extraction of a 3D model or 3D information. The 3D+ approaches are related to the 3D of the internal structures or using multispectral illumination or extended focus.

3D/3D+ workflow

- The decision in the first branches will select between volume digitisation or surface digitisation.
- The second branch in the surface digitisation will select between multispectral digitisation and visible spectrum digitisation.
- The third branch in the visible spectrum prioritises the shape or the texture (colour information).
- The fourth branches are related to the size of the specimen:
  - for colour priority
    - the category of specimens with a size smaller than 2 mm recommends the use of microCT with the mapping of 2D stacked images.
    - the specimens / objects with a size between 2 mm and 8 cm relate to the setups combining photo stacking and photogrammetry.
    - the specimens / objects with a size bigger than 8 cm apply to the setups of photogrammetry.
  - for shape priority
    - the category of specimens with a size smaller than 2 mm recommends

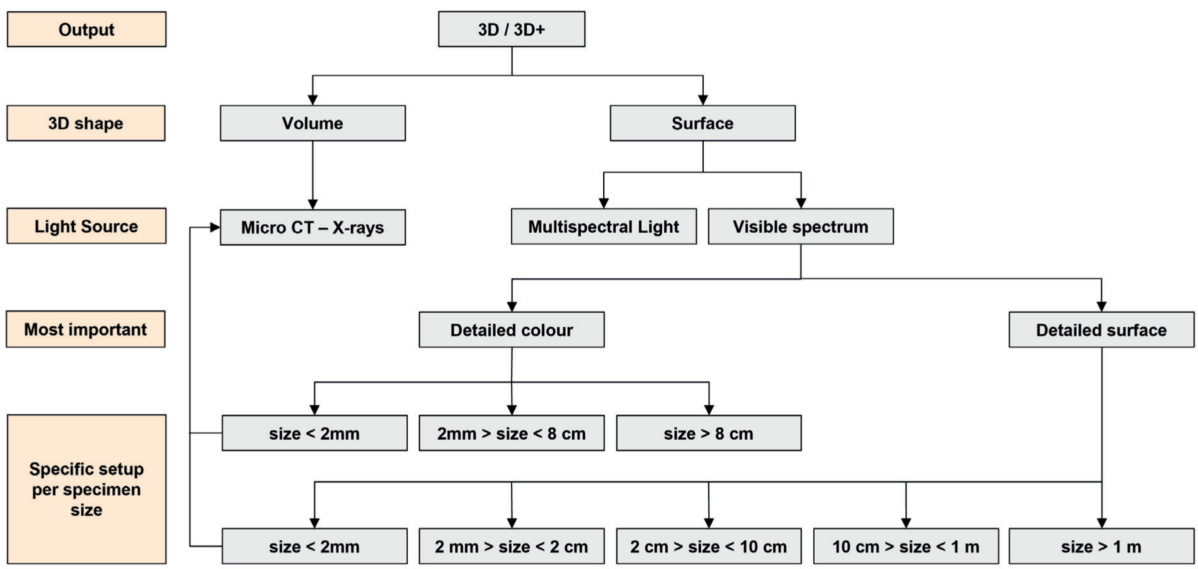

Fig. 4. The hierarchical structure of the 3D/3D+ part of the DIGIT-KEY.

- the use of microCT with the surface reconstruction.
- the specimens/objects with a size between 2 mm and 2 cm refer to the
- setups combining photo stacking and photogrammetry.
- the specimens/objects with a size between 2 cm and 10 cm can follow
- three workflows using
  - a high resolution structured light scanner with automatic 3D reconstruction
  - a very high resolution structured light microscope with manual reconstruction
  - if the quality of the mesh is of equal importance than the texture, use the workflow of SfM Photogrammetry
- The specimens/objects with a size between 10 cm and 1 m can follow three workflows using
  - a high resolution (about 10 µm) structured light scanner with automatic 3D reconstruction
  - a very good resolution (about 100 µm) handled or fixed structured light scanner with automatic 3D reconstruction
  - if the quality of the mesh is of equal importance than the texture, use the workflow of SfM Photogrammetry
- The specimens/objects with a size bigger than 1 m can follow three workflows using
  - the combination of several scans with very good accuracy (about 100 µm) with manual 3D reconstruction
  - the combination of several scans with good accuracy (about 200–500 µm) with automatic 3D reconstruction
  - the combination of several scans with an accuracy about 1 mm with automatic 3D reconstruction

As another example, for the digitisation of a bone or fossil of about 20 cm which requires a 3D model which has an excellent texture and a good mesh representing some details, the following pathway will be followed:

1. The collection or specimen has to be digitised in:
   - 3D
2. The specimen has to be visualised in 3D and:
   - only the surface is of importance
3. 3D surface digitisation
   - the surface of the specimen has to be digitised showing details in the mesh (3D volume or texture (3D vcolour of the specimen) that are visible
   - in visible spectrum
4. The 3D digital twin of the specimen must show the detailed texture (the colour information) of the specimen
   - D digitisation Photogrammetry Structure from Motion (SfM)
     - the size of the specimen is > 8 cm

Unfortunately, there is no digitisation technique used among the partners which combines the best shape and texture. After the initial choice of the main digitisation approach, the DIGIT-KEY helps the user to decide which technique suits best based on colour information of the final product for both 2D/2D+ and 3D/3D+ approaches and also on accuracy of the mesh (3D model) for presented 3D/3D+ techniques. This is done by using two sets of symbols related respectively to the mesh quality and the texture quality (Fig. 5).

Each workflow links to a list of digitisation setups offering the required criteria of digitisation. At the moment, there are 49 setups present in the Digit-Key (Table 1). Some of these setups are unique among the SYNTHESYS+ Task 7.2 (JRA2) partners, e.g., prototypes or microCT scanners. Some others are already used by several institutions e.g. a handled surface scanner like Artec Spider.

If a user wishes to browse through the present digitisation setups for a certain technique or partner (Table 1), this is possible through one of the shortcut menus found at the right side of the DIGIT-KEY as seen in Fig. 2. For each technique or partner an overview is given of the present techniques. If a setup needs to be added in the key, this can be done by clicking on the 'add setup' button. A new tab will open where the registered user can fill out the necessary information to create the new setup page.

In each technique, the registered user can add a new setup, fill the information and categorise it with tags. For each digitisation setup, the key provides information divided in 4 sections:

- Default
  - Title: title of the equipment, displayed in the dynamic lists
  - Summary: short description of the method, displayed in the dynamic lists
  - Shape and texture: following the Fig. 5
  - Equipment: text description
  - Transportability: choice
    - portable (can be moved easily in a public transport)
    - transportable in a car
    - transportable in a truck
    - not transportable
  - Stuff training: choice
    - basic training
    - elaborate training
    - specialist
  - Training / manual URL: link

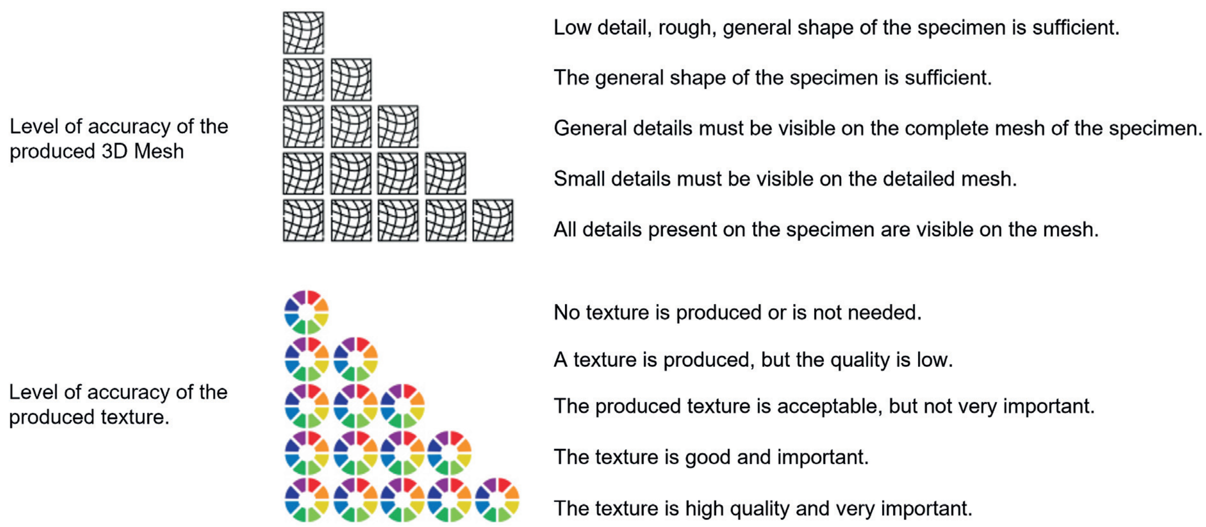

Fig. 5. Within the DIGIT-KEY to distinguish and compare the level of accuracy of the produced 3D mesh or texture (colour rendering of a 3D model) a 5 symbol indication has been made. Above: level of detail of the shape of the produced 3D model; below: level of accuracy of the produced texture of the 3D model.

- Description
  - Best resolution: text line
    e.g., 65 µm
  - Size of the objects: text Line
    e.g., 30 cm × 20 cm × 12 cm
  - Illustrated description: rich text with illustration(s), table(s) and link(s)
  - Results: rich text with illustration(s), table(s) and link(s)
    Example(s) of results obtained with the digitisation setup for different types of collections
  - Use-cases: rich text with illustration(s), table(s) and link(s)
    Description of the different use-cases where the setup is appropriate
  - References: rich text with illustration(s), table(s) and link(s)
    List of references describing or using the setup. It could also be a link to a list of references in an external system
- Pipeline
  - Digitisation procedure: rich text with illustration(s), table(s) and link(s)
    Description of the digitisation workflow
  - Available metadata: rich text with illustration(s), table(s) and link(s)
  - Open Source software: rich text with illustration(s), table(s) and link(s)
    List of the Open Sources software which can be used in the workflow and/or the viewing/analysis of the digitised data.
  - Open Source software: rich text with illustration(s), table(s) and link(s)
    List of the Open Sources software which can be used in the workflow and/or the viewing/analysis of the digitised data.
  - Commercial packages: rich text with illustration(s), table(s) and link(s)
    List of the Commercial packages which are used in the workflow and/or the viewing/analysis of the digitised data.
  - Standardisation protocols: rich text with illustration(s), table(s) and link(s)
    Which digitisation protocols, specimen and metadata, are standardised and how.
  - Semantics: rich text with illustration(s), table(s) and link(s)
    Explanation of the different steps in the standardisation protocols
  - Storage capabilities: rich text with illustration(s), table(s) and link(s)
    Which storage facilities exist or are used at the digitisation institute for the given technique
  - Data access: rich text with illustration(s), table(s) and link(s)
    Description of the possible ways to access the data remotely
  - Data/image analysis: rich text with illustration(s), table(s) and link(s)
    After digitisation, which options exist to analyse the produced data
- Cost(s)
  - Human time: text
  - Computing time: text
  - Equipment cost (purchase cost) (€): text
  - Cost full description: text

The complete cost full description is in private publication state and only available for authenticated users with an ad hoc role. In a private file the following divisions can be found:

  - Purchase cost of the equipment (approximative if a legal clause exists which prohibits to share the exact cost): text, amount in (€) Euros
  - Depreciation period: text
  - Time after which a machine is supposed to be replaced

- ○ Space needed (m^2): text
- ○ Number of square metres needed to use the equipment
- ○ Room rental (€)
- ○ Cost to rent the needed space to use the digitisation equipment
- ○ Institutional costs (e.g., overheads, electricity) (€): text
- ○ % of the income of each service contract
- ○ Software licenses (€): text
- ○ Cost for software to run the digitisation technique or to process the produced digitisation files
- ○ Staff costs (% of FTE): text
- ○ Percentage of staff, expressed in Full Time Equivalents (FTE's), to run the digitisation equipment during a complete day
- ○ Regular maintenance costs (€): text
- ○ Maintenance cost(s) needed to keep the equipment fully functional in time
- ○ Consumables (labels, pins, containers, chemicals) (€): text
- ○ Cost of disposables used while operating the digitisation technique
- ○ Storage costs (€): text
- ○ Cost to store the digital files produced by the digitisation technique used
- ○ Cost(s) full description: text
- ○ Purchase cost + maintenance costs

Besides the information for each digitisation technique and setup in the DIGIT-KEY, the user will find 18 user manuals which describe the different digitisation workflows (Table 1) and a list of selected bibliographic references proposed for the different techniques.

Discussion

The DIGIT-KEY presented here is intended to be a sustainable tool for deciding which 2D, 2D+ or 3D digitisation technique is most appropriate for digitising a specimen or complete collection depending on a specific expected outcome. This is supported on the provided texture (colour information) of the virtual specimen and the details present in the mesh for 3D and 3D techniques.

Thanks to the collaboration of several SYNTHESYS+ partners most of the available techniques used for digitisation of natural and cultural history collections are covered. The DIGIT-KEY provides information about 49 setups divided in 9 techniques and can be easily extended to new setups and techniques (Table 1).

For almost every collection type, multiple solutions are presented. But we are aware that there are still techniques used in other natural history institutions that are not listed in the current DIGIT-KEY. Therefore, more partners within DiSSCo, but also globally beyond Europe should add their techniques and workflows to make it even more complete. The DIGIT-KEY is currently the foundation of a resource which can be further developed for re-use and standardisation.

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