

ARCHEOLOGIE DE TERRAIN

(fouille, prospection, télédétection)

Josef Wilczek

josef.wilczek@sorbonne-universite.fr



Document confidentiel –
ne peut être reproduit ni diffusé
sans l'accord préalable
de Sorbonne Université.

Introduction

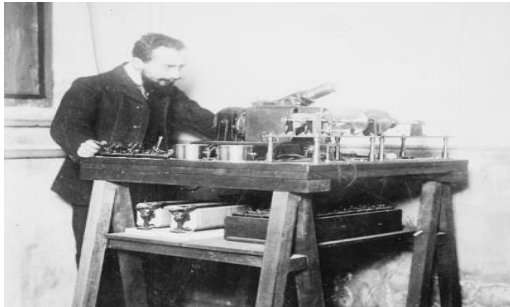
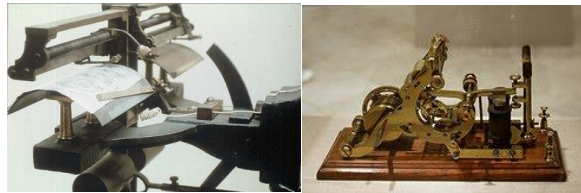
Planning

- 1) Introduction + Prospection
- 2) **Documentation en 3D** + Chantier
- 3) Artefacts (céramique, métallique, lithique, verre, textile)
- 4) Hommes et animaux (anthropologie et zoologie)
- 5) Végétaux et microfossiles

Documentation en 3D

Les principes de la 3D, sont-ils nouveaux ?

19^{ème} siècle



Jusqu'à 1980

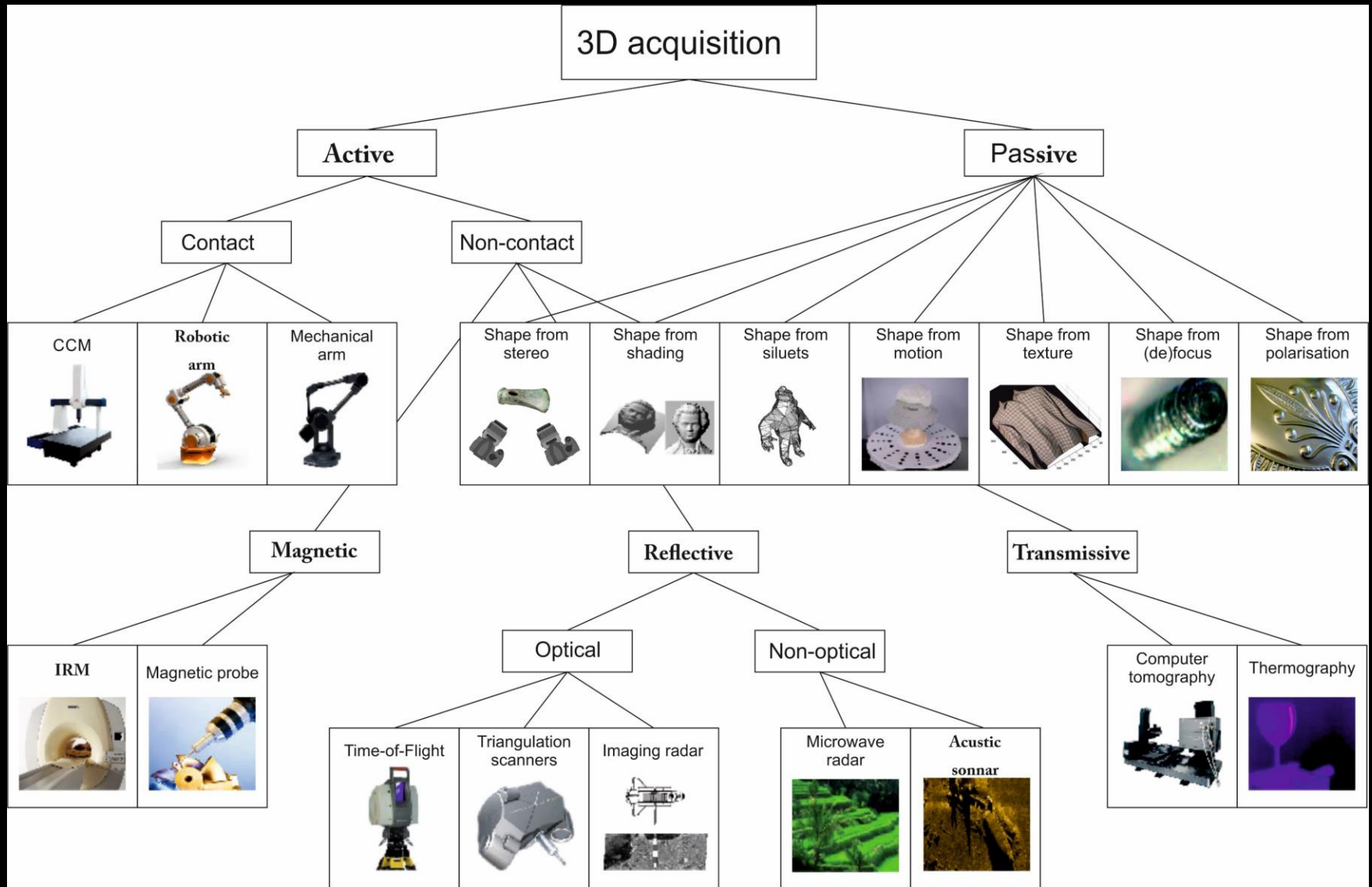


A partir de 1990



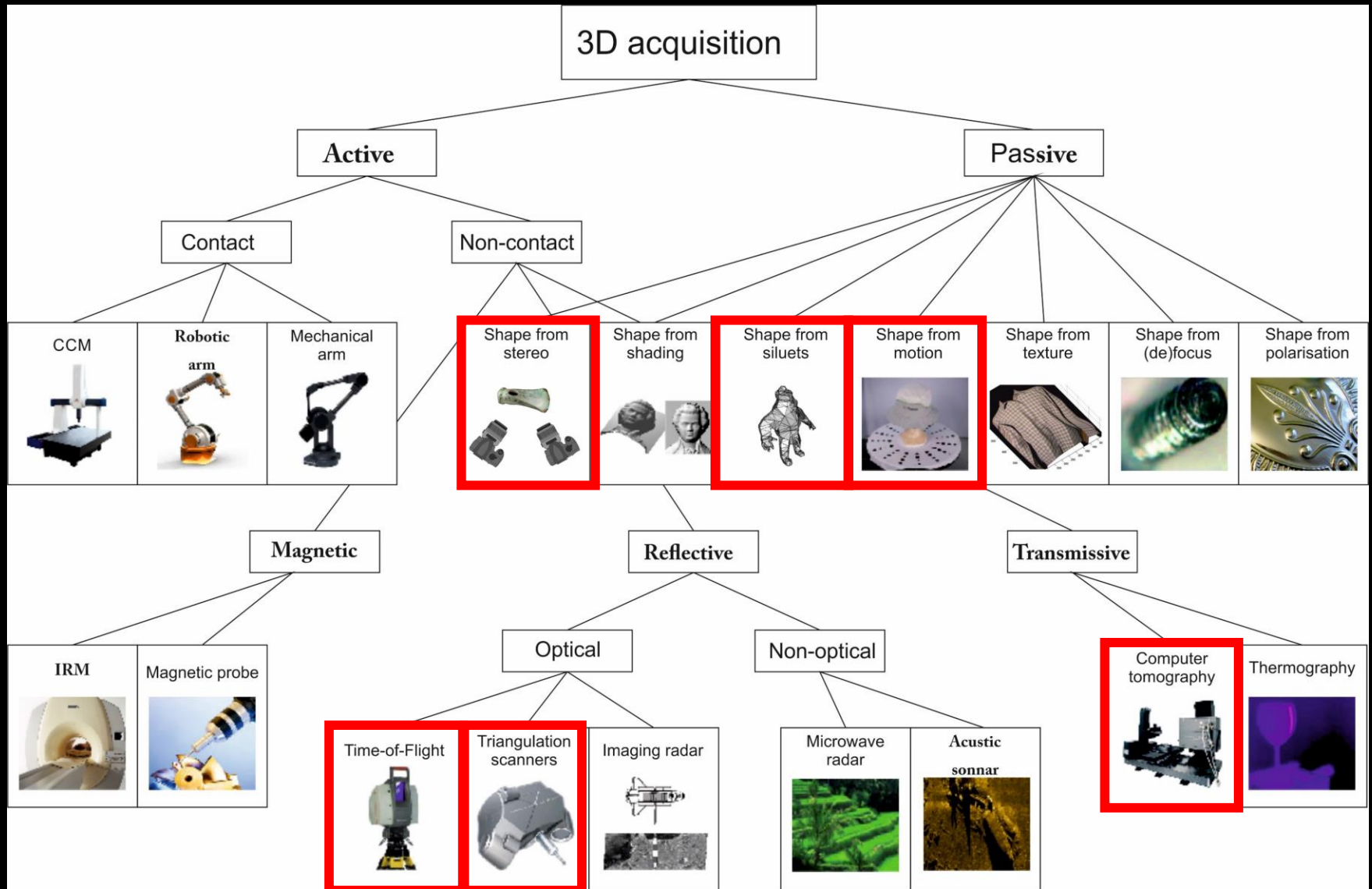
Documentation en 3D

Quelles technologies peut-on utiliser pour faire la 3D ?



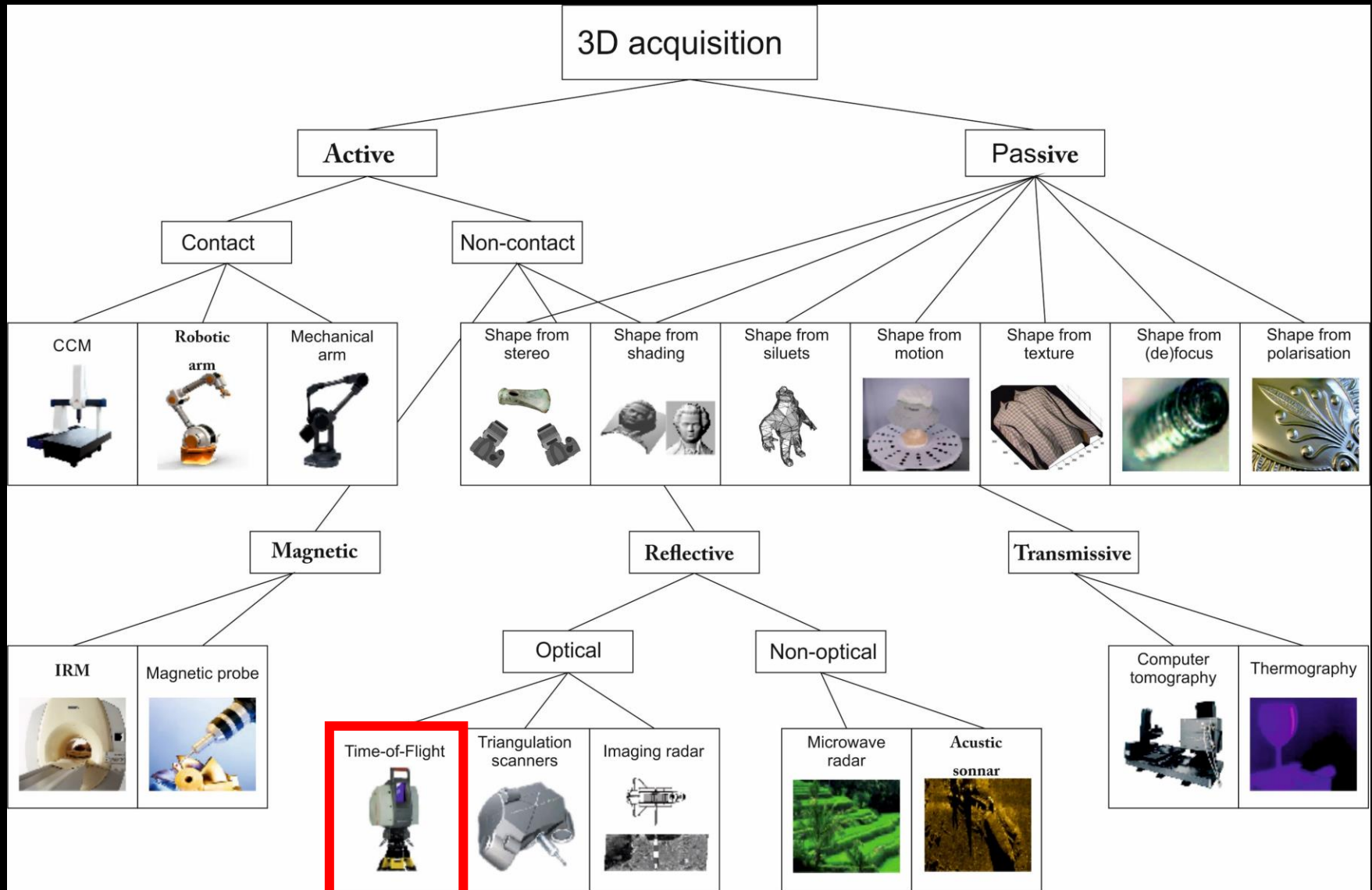
Documentation en 3D

Quelles technologies peut-on utiliser pour faire la 3D ?



Documentation en 3D

Quelles technologies peut-on utiliser pour faire la 3D ?

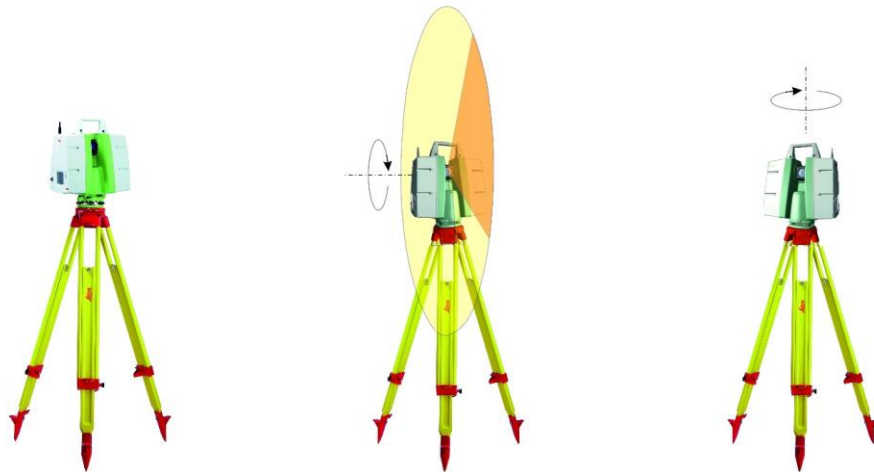


Documentation en 3D

Temps du vol / Time-of-Flight (ToF)

⇒ A quoi ça ressemble ?

Appareil



Quelques exemples

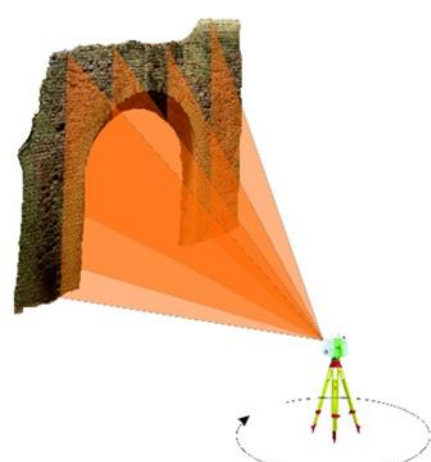
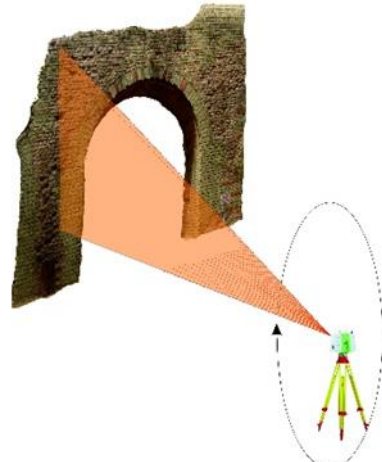
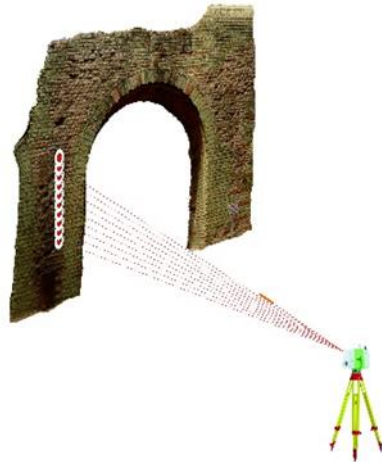
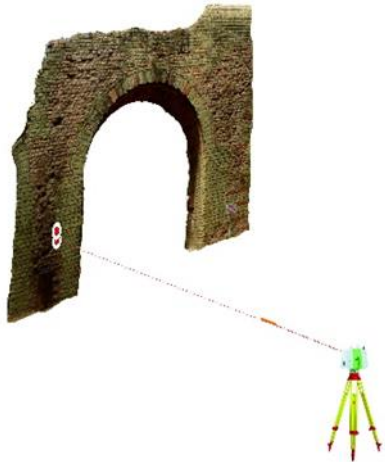


Leica / Trimble / FARO

Documentation en 3D

Temps du vol / Time-of-Flight (ToF)

⇒ Comment ça marche ?



Documentation en 3D

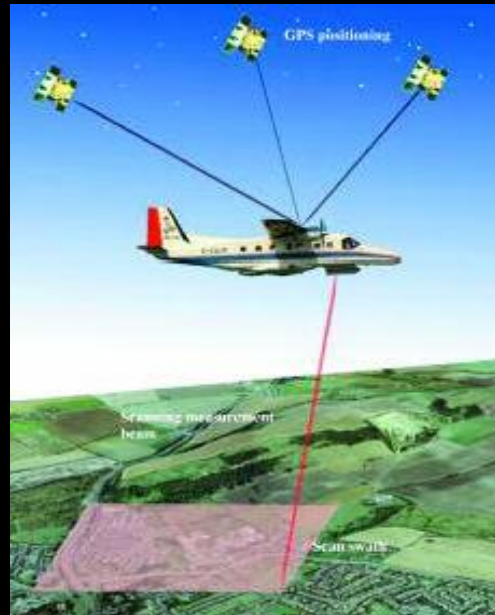
Temps du vol / Time-of-Flight (ToF)

⇒ LiDAR (Light Detection and Ranging)

Terrestre



Aérienne



Avion



Drone

Documentation en 3D

Temps du vol / Time-of-Flight (ToF)

⇒ A quoi ça sert ?

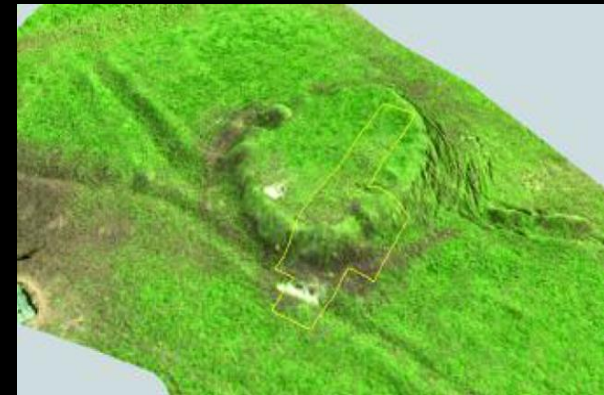
Bâtiments / Structures



Chantiers



Prospection

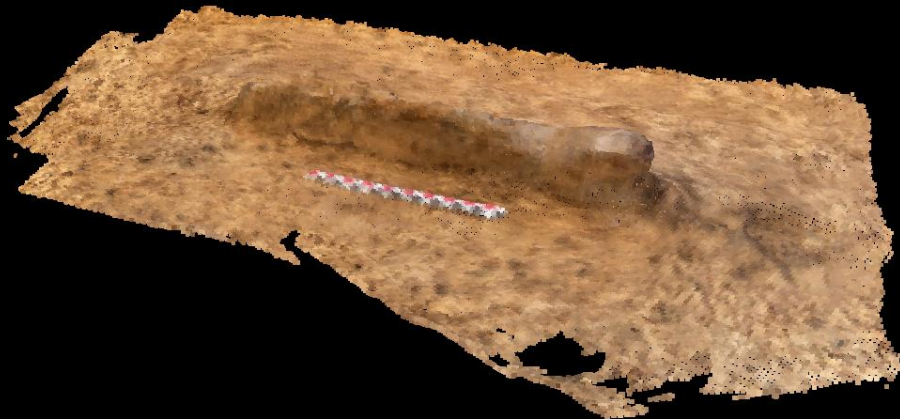


Documentation en 3D

Temps du vol / Time-of-Flight (ToF)

⇒ A quoi ça sert ?

Artefacts / Chantier



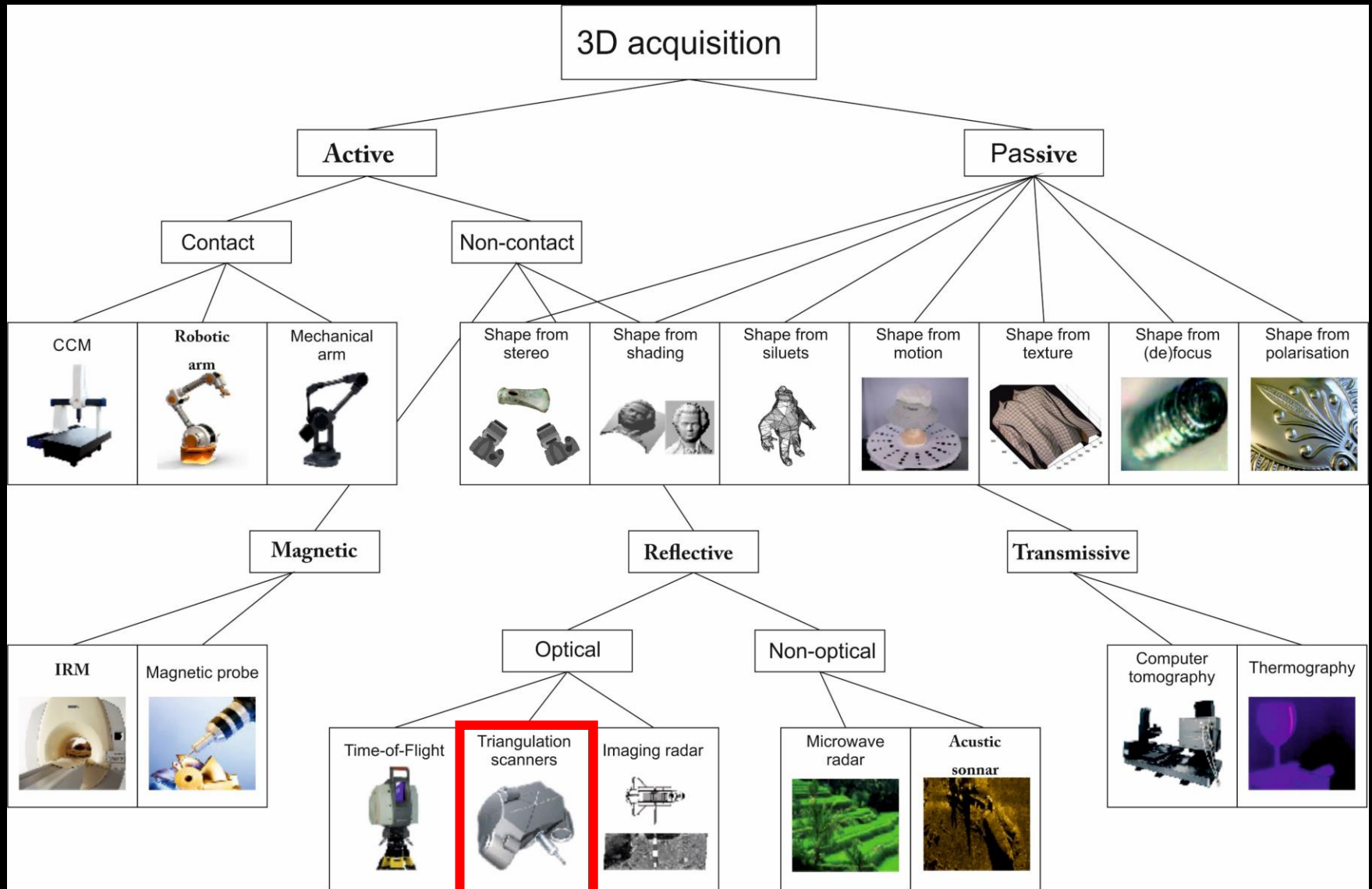
iPhone 12+/13

LiDAR Scanner



Documentation en 3D

Quelles technologies peut-on utiliser pour faire la 3D ?



Documentation en 3D

Triangulation active (scanneurs laser surfaciques)

⇒ A quoi ça ressemble ?

Appareil



Quelques exemples

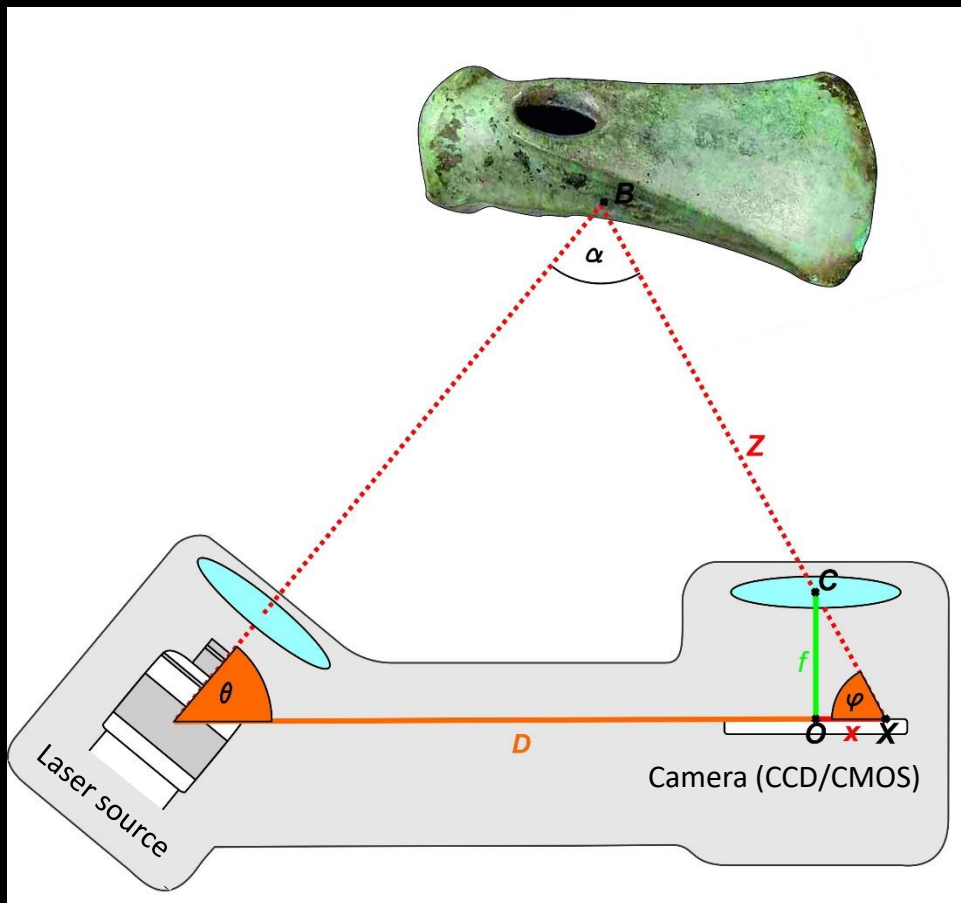


Minolta / Leica / Trimble / FARO, ...

Documentation en 3D

Triangulation active (scanneurs laser surfaciques)

⇒ Comment ça marche ?



On a un point B sur l'objet et on veut connaître ses coordonnées

On utilise le scanneur laser qui est composé de deux parties

- une source du laser
- une camera (c'est elle qui capte la lumière du laser)

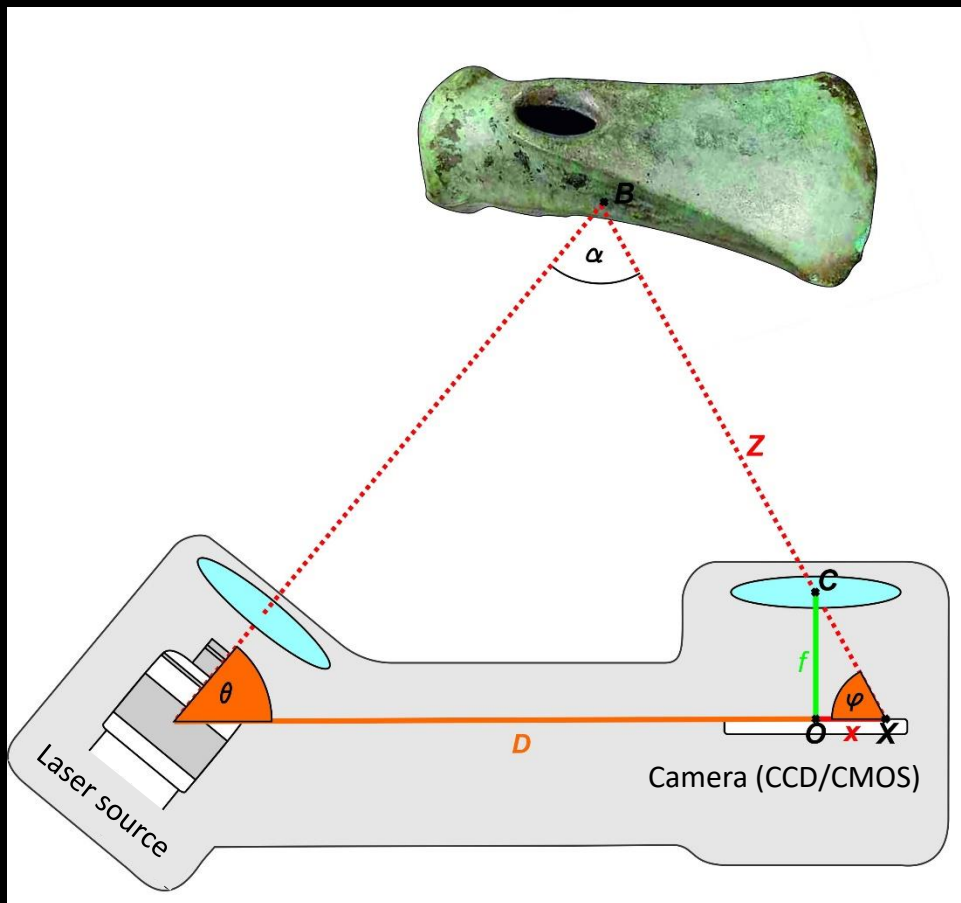
Cet appareil est calibré, c.-à-d. qu'on connaît la position et l'orientation de toutes les parties. On connaît:

- La distance entre laser et camera (D) et leur orientations (θ et φ)
- La position du centre d'optique de camera (C)
- La position du centre de capteur de camera (O)
- La distance focale de camera (f)

Documentation en 3D

Triangulation active (scanneurs laser surfaciques)

⇒ Comment ça marche ?



Si le laser est projeté sur l'objet en point B et ce point B est capté par le capteur de camera en point X, on peut calculer ce distance Z qui nous intéresse en passant par la trigonométrie....

$$\frac{D+x}{\sin \alpha} = \frac{D+x}{\sin (\theta+\varphi)} = \frac{Z}{\sin \theta}$$

$$\varphi = \arctan \frac{f}{x}$$

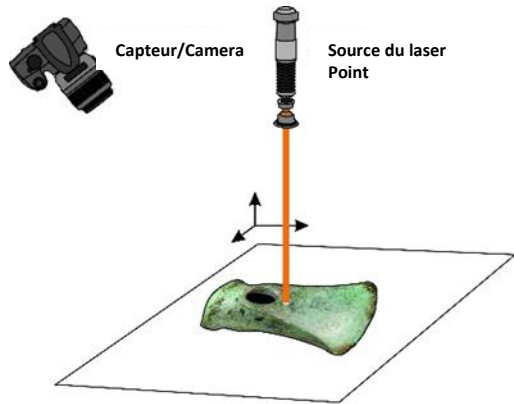
$$Z = (D+x) \frac{\sin \theta}{\sin \left(\theta + \arctan \frac{f}{x} \right)}$$

Documentation en 3D

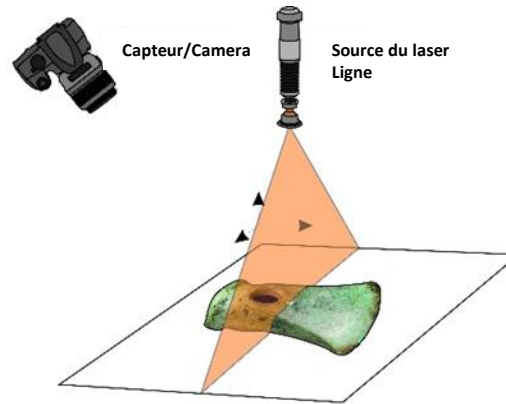
Triangulation active (scanneurs laser surfaciques)

⇒ Comment ça marche ?

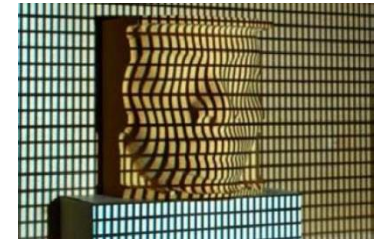
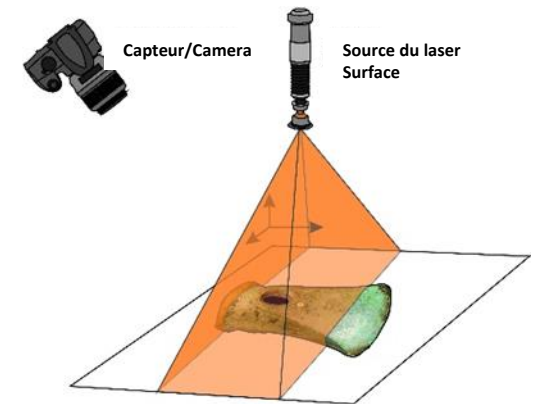
Point



Ligne



Surface

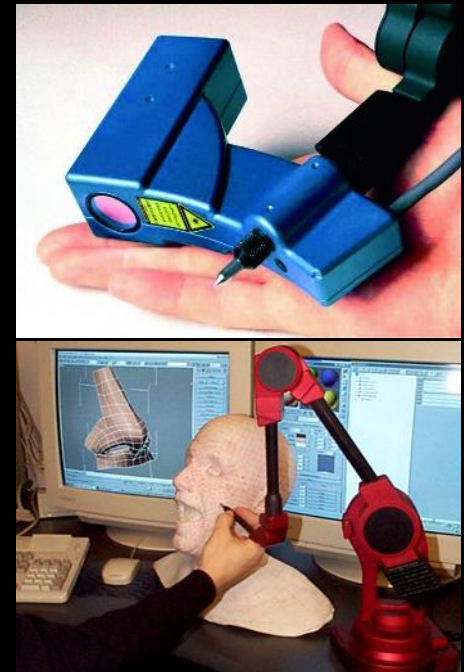


Documentation en 3D

Triangulation active (scanneurs laser surfaciques)

⇒ Comment ça marche ?

Microscribe + Microscan (2007)

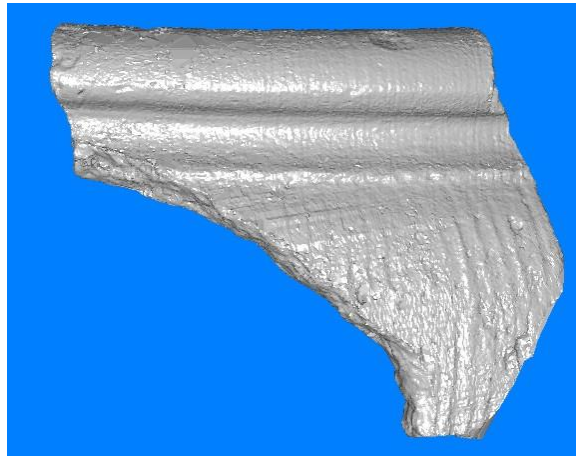
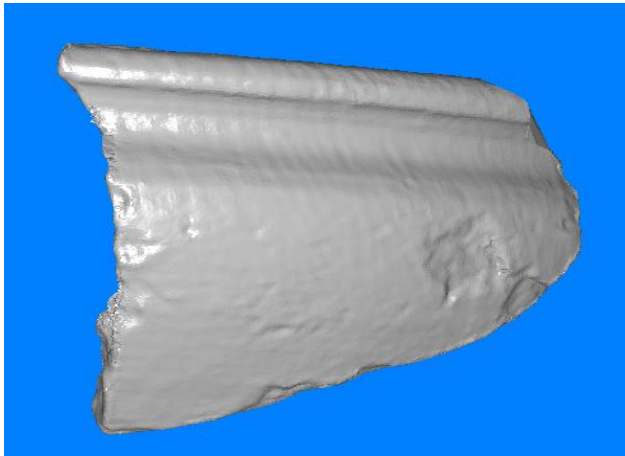


Documentation en 3D

Triangulation active (scanneurs laser surfaciques)

⇒ Comment ça marche ?

Microscribe + Microscan (2007)

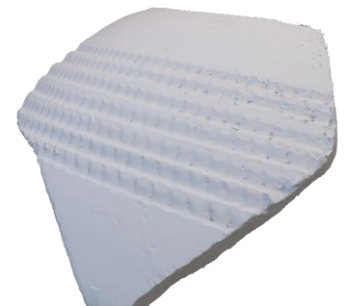
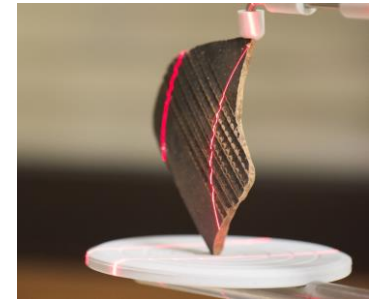
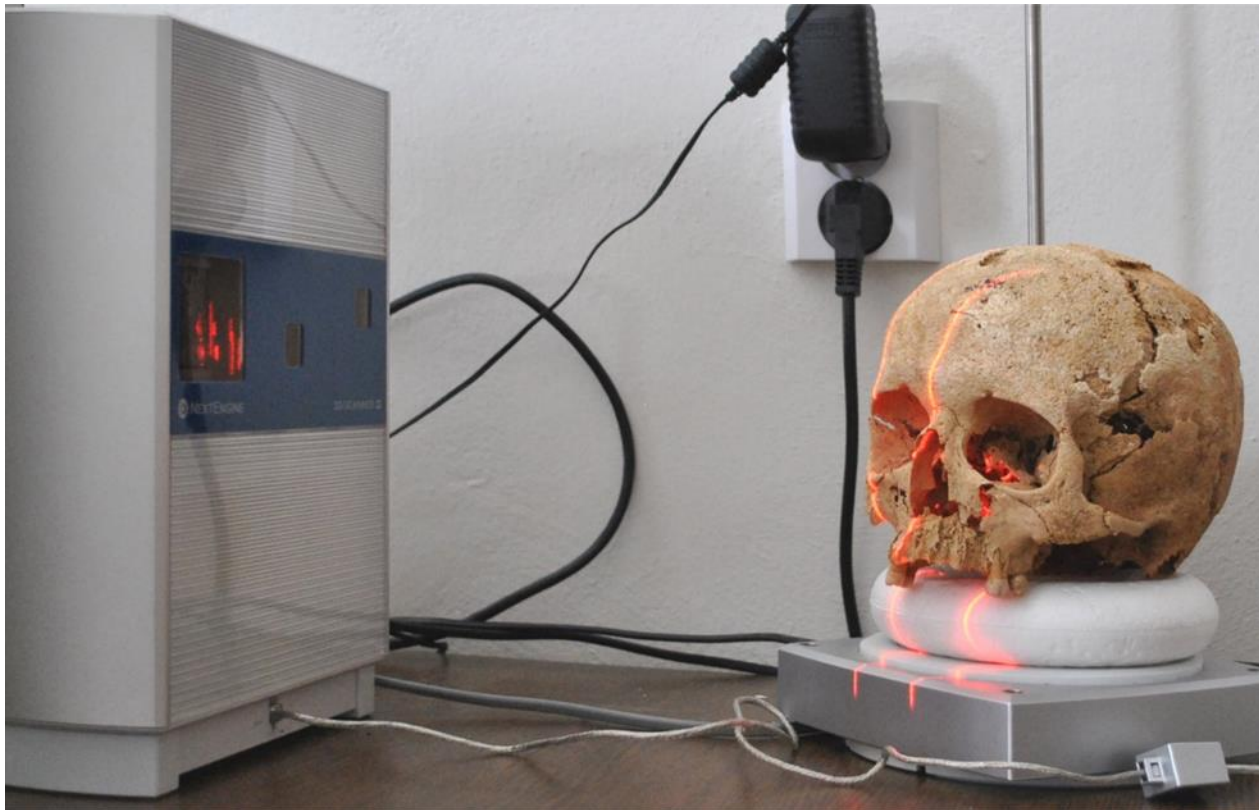


Documentation en 3D

Triangulation active (scanneurs laser surfaciques)

⇒ Comment ça marche ?

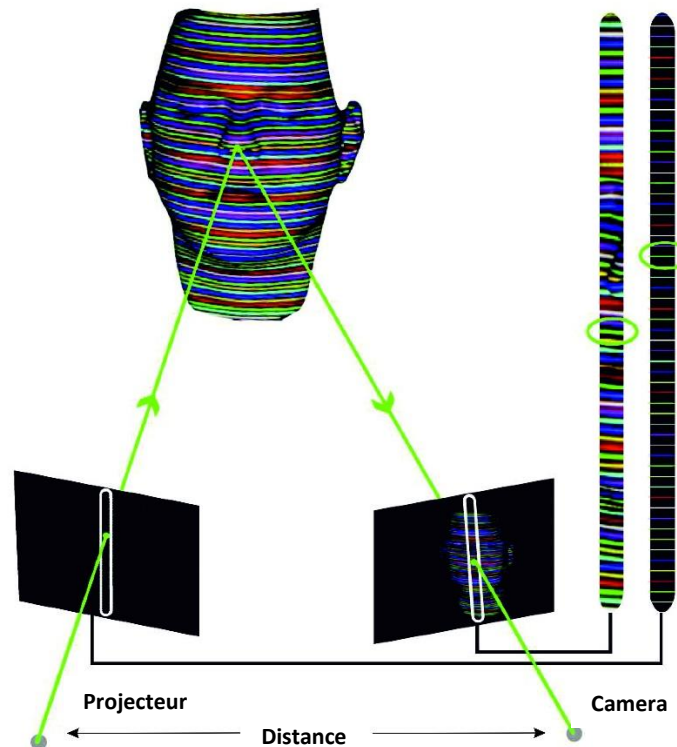
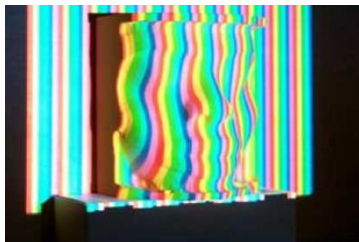
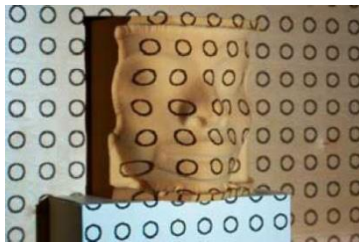
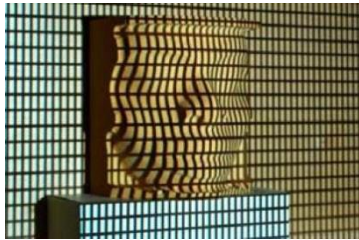
Nextengine (2008)



Documentation en 3D

Triangulation active

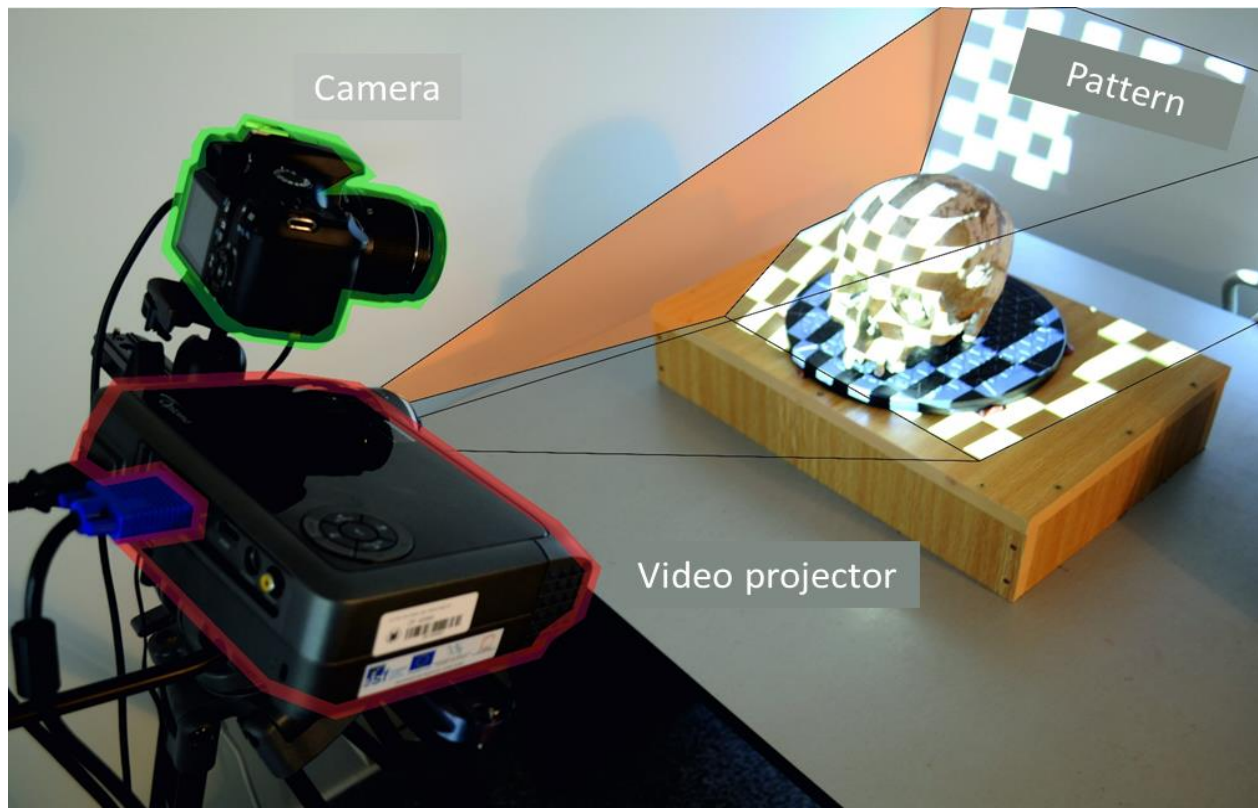
⇒ Lumière structurée



Documentation en 3D

Triangulation active
⇒ Lumière structurée

Mephisto (2012)



Documentation en 3D

Triangulation active
⇒ Lumière structurée

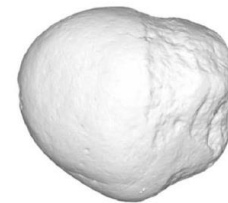
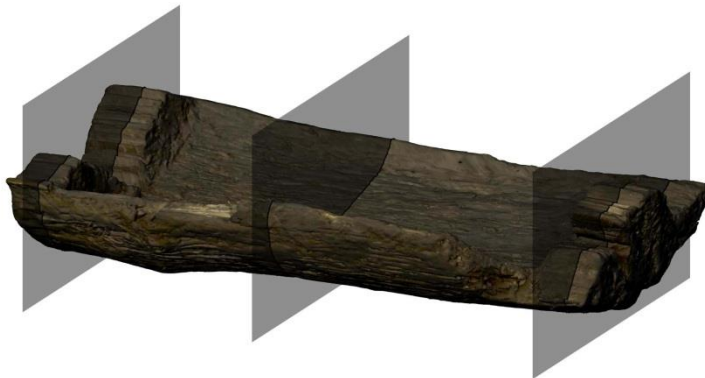
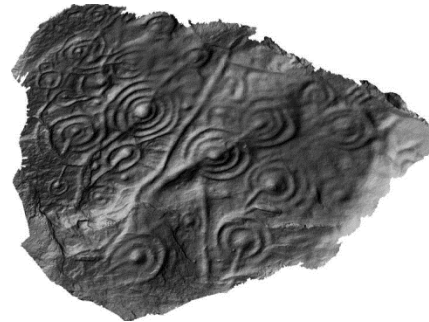
Einscan (2015)



Documentation en 3D

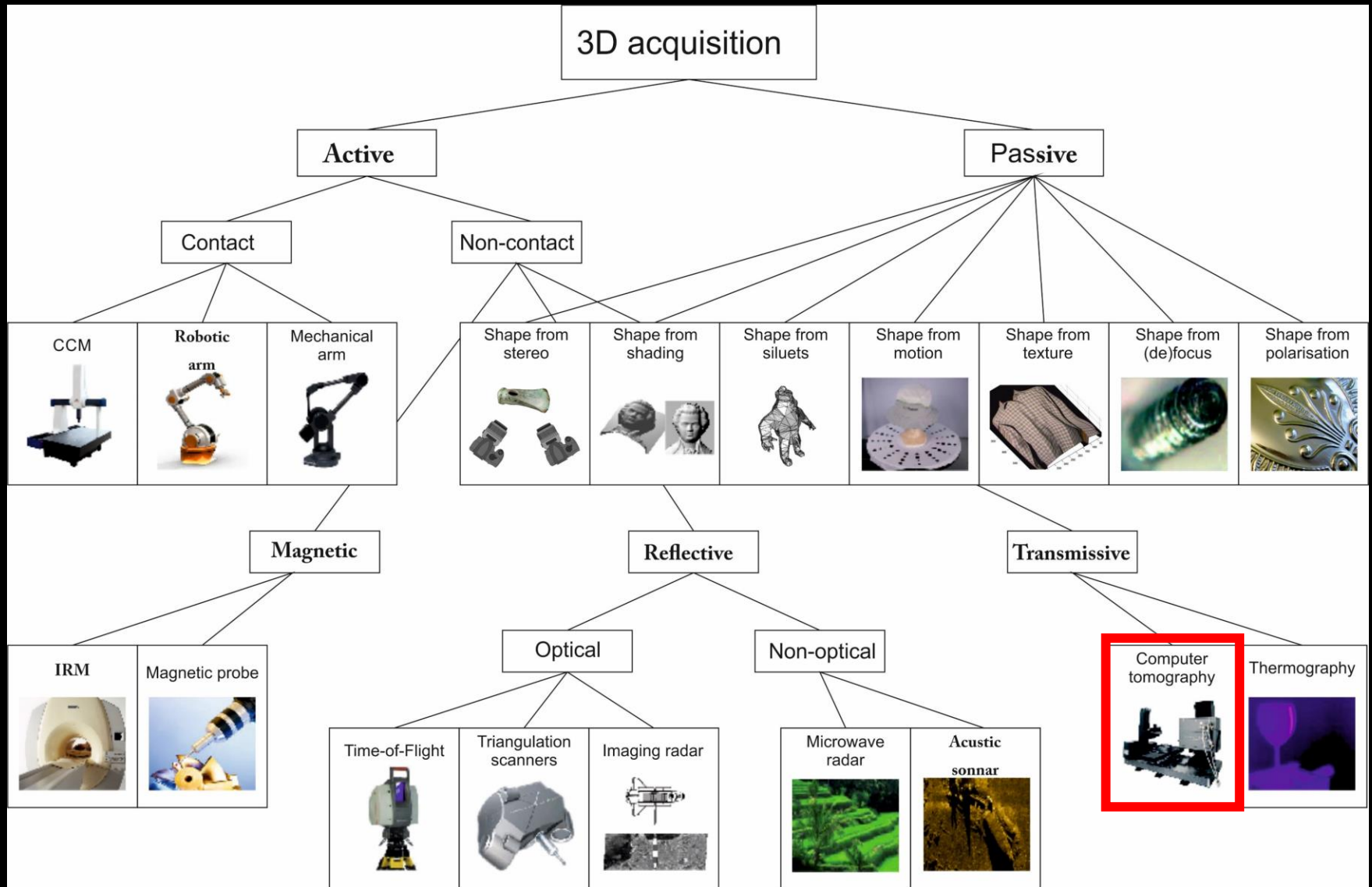
Triangulation active

⇒ Lumière structurée



Documentation en 3D

Quelles technologies peut-on utiliser pour faire la 3D ?



Documentation en 3D

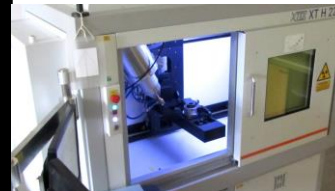
Tomodensitométrie (Computed Tomography - CT)

⇒ A quoi ça ressemble ?

Quelques exemples



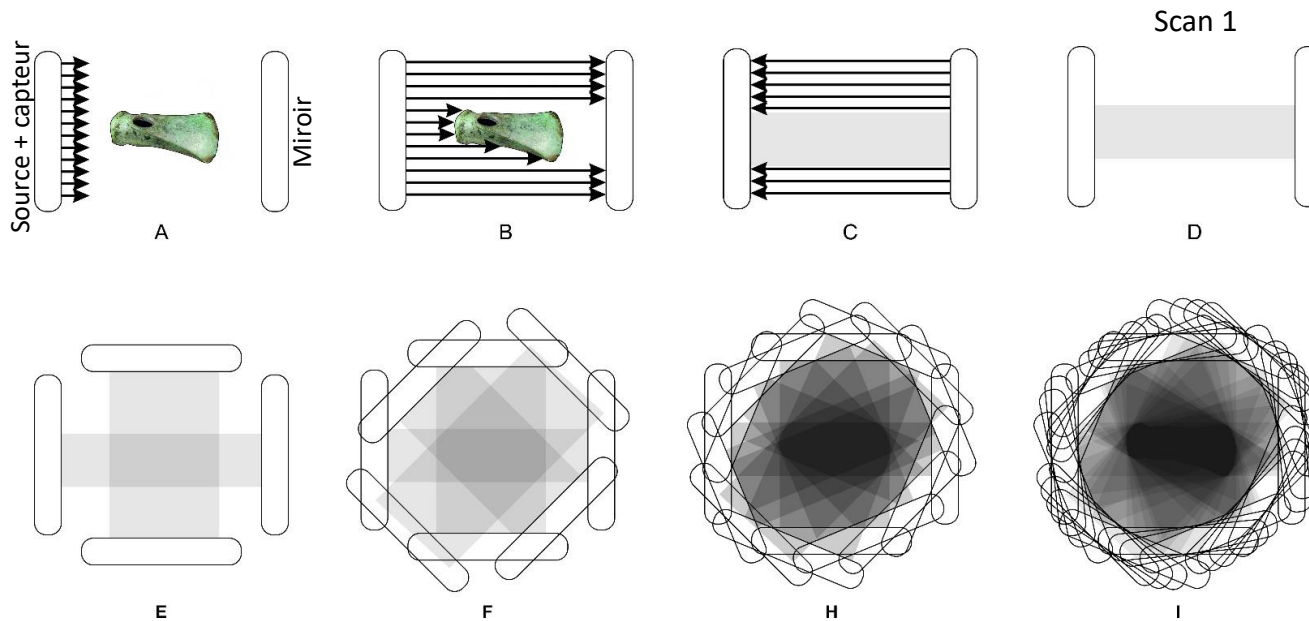
Quelques exemples (micro-CT)



Documentation en 3D

Tomodensitométrie (Computed Tomography - CT)

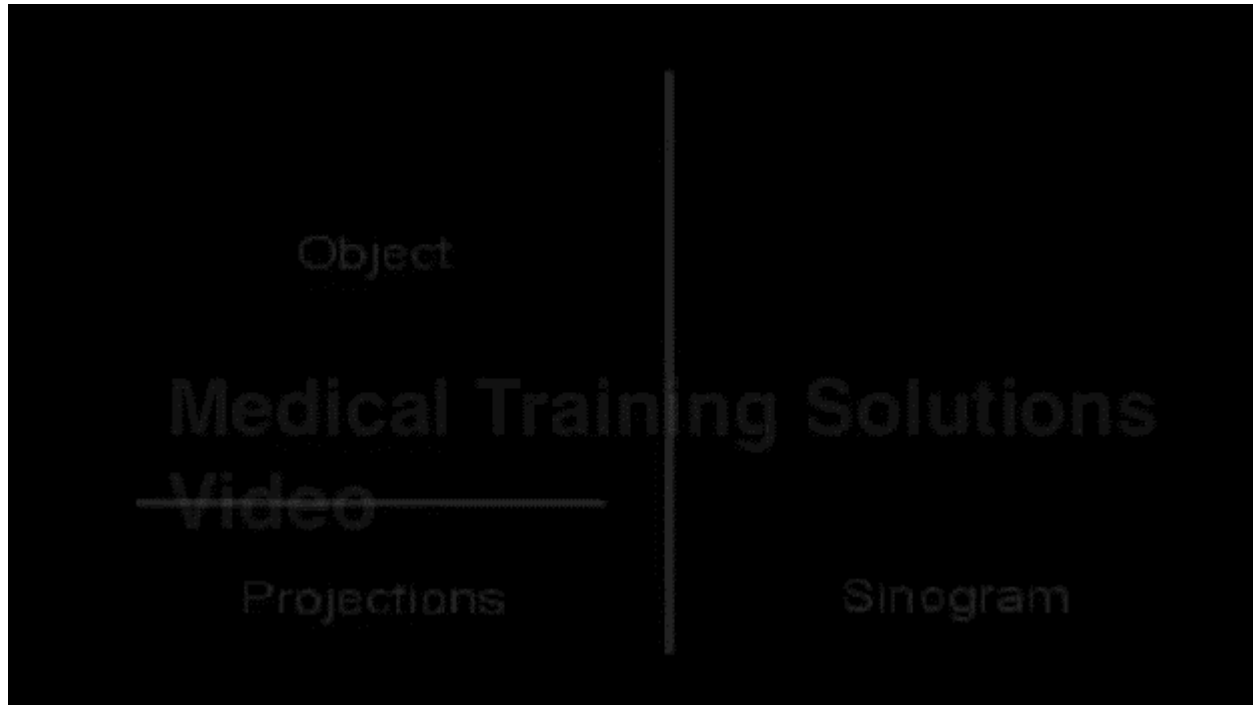
⇒ Comment ça marche ?



Documentation en 3D

Tomodensitométrie (Computed Tomography - CT)

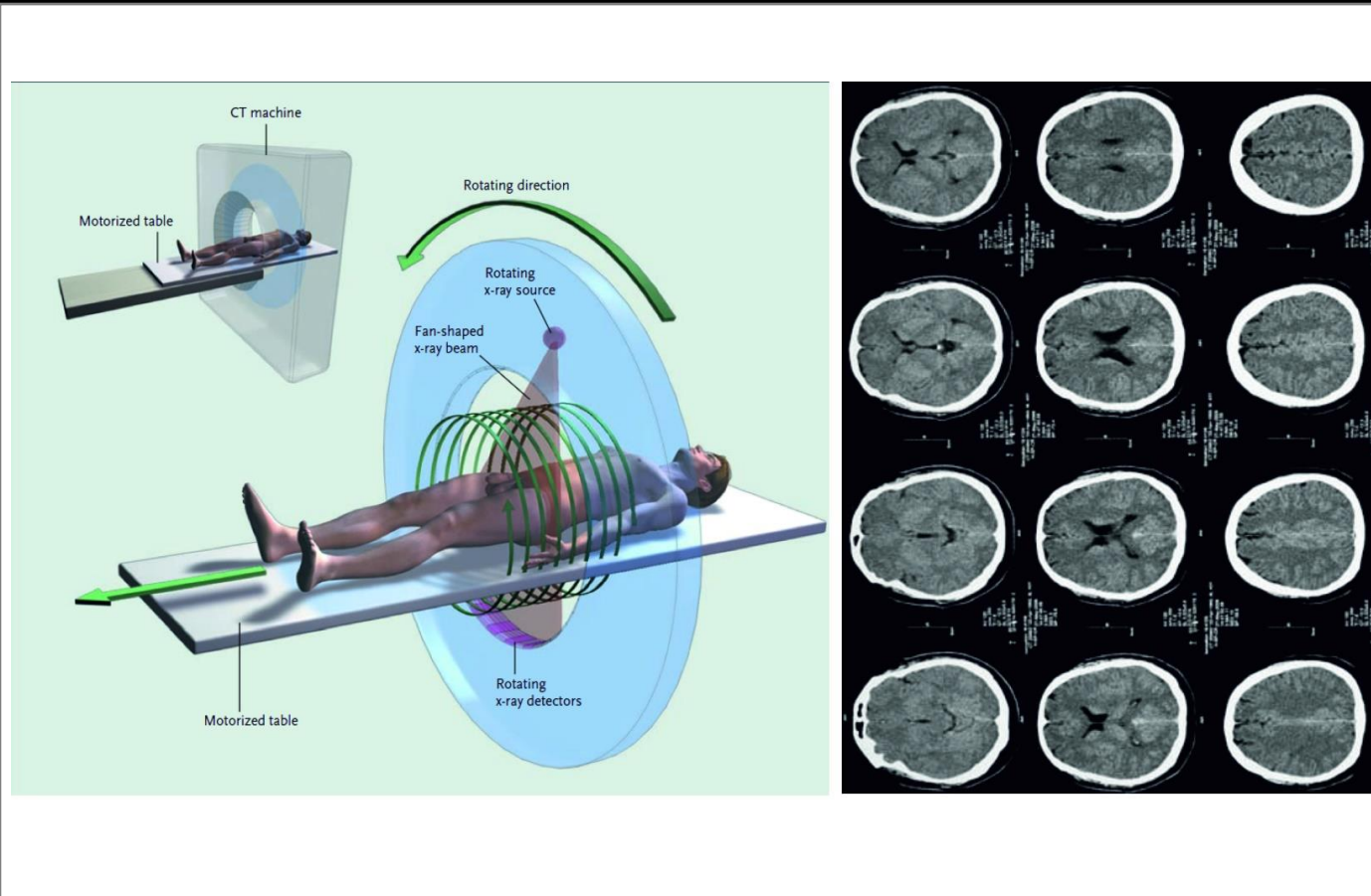
⇒ Comment ça marche ?



Documentation en 3D

Tomodensitométrie (Computed Tomography - CT)

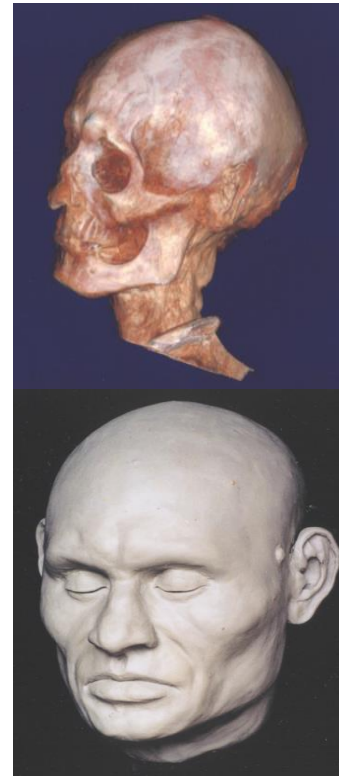
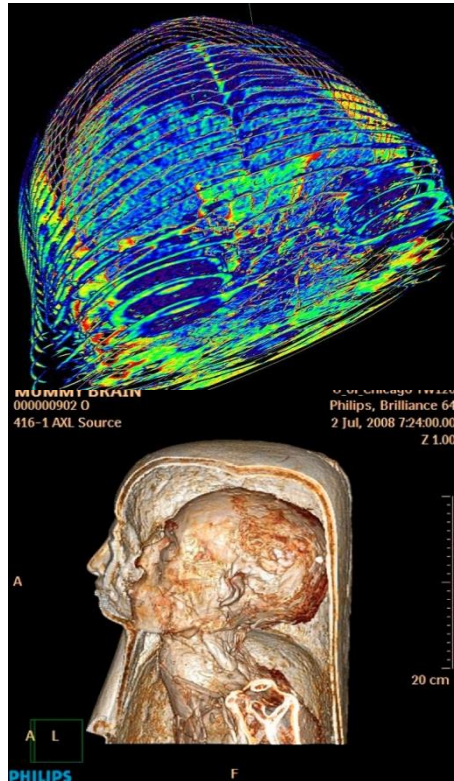
⇒ Comment ça marche ?



Documentation en 3D

Tomodensitométrie (Computed Tomography - CT)

⇒ A quoi ça sert ?

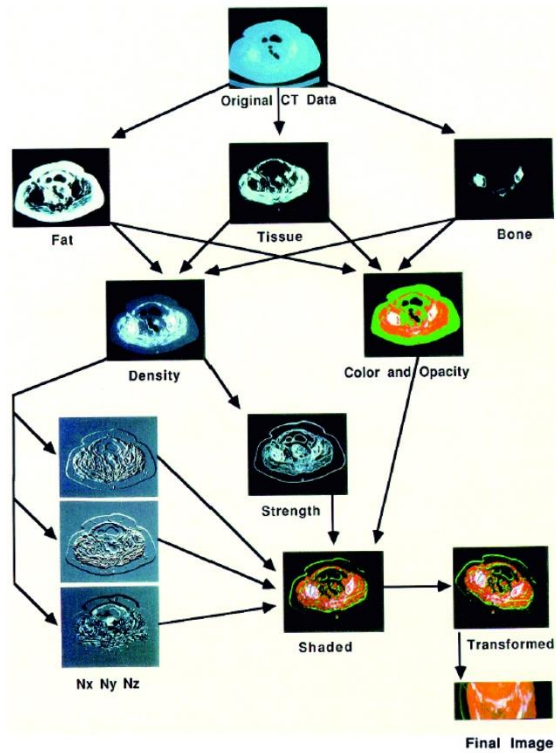


Documentation en 3D

Tomodensitométrie (Computed Tomography - CT)

⇒ A quoi ça sert ?

Segmentation/Fenêtrage / Endoscopie

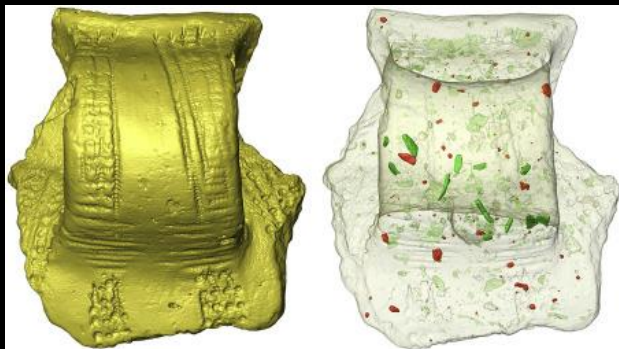
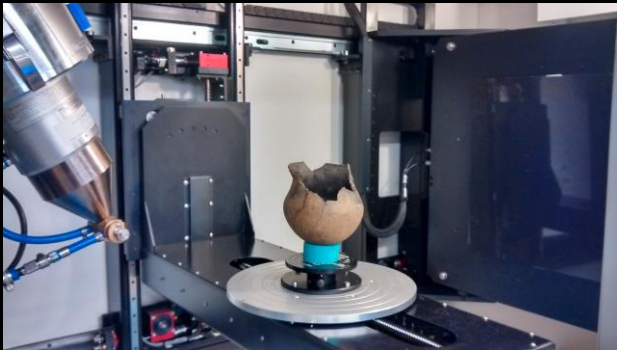


Documentation en 3D

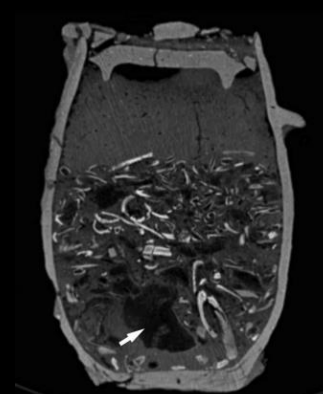
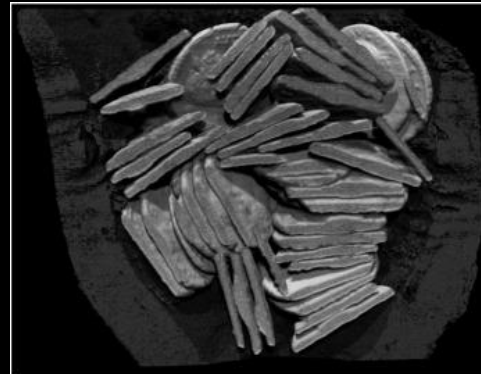
Tomodensitométrie (Computed Tomography - CT)

⇒ A quoi ça sert ?

Artefacts



Structures (dépôts / tombes)



Documentation en 3D

Tomodensitométrie (Computed Tomography - CT)

⇒ Quelques exemples



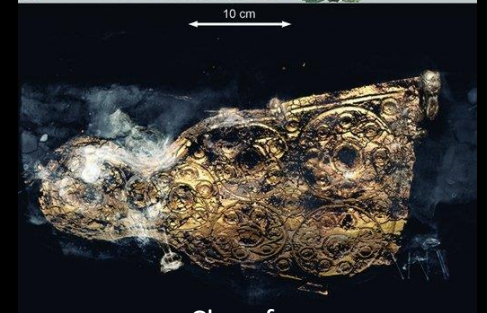
Chantiers (Keltenblock)



Chantier



Ceinture en bronze



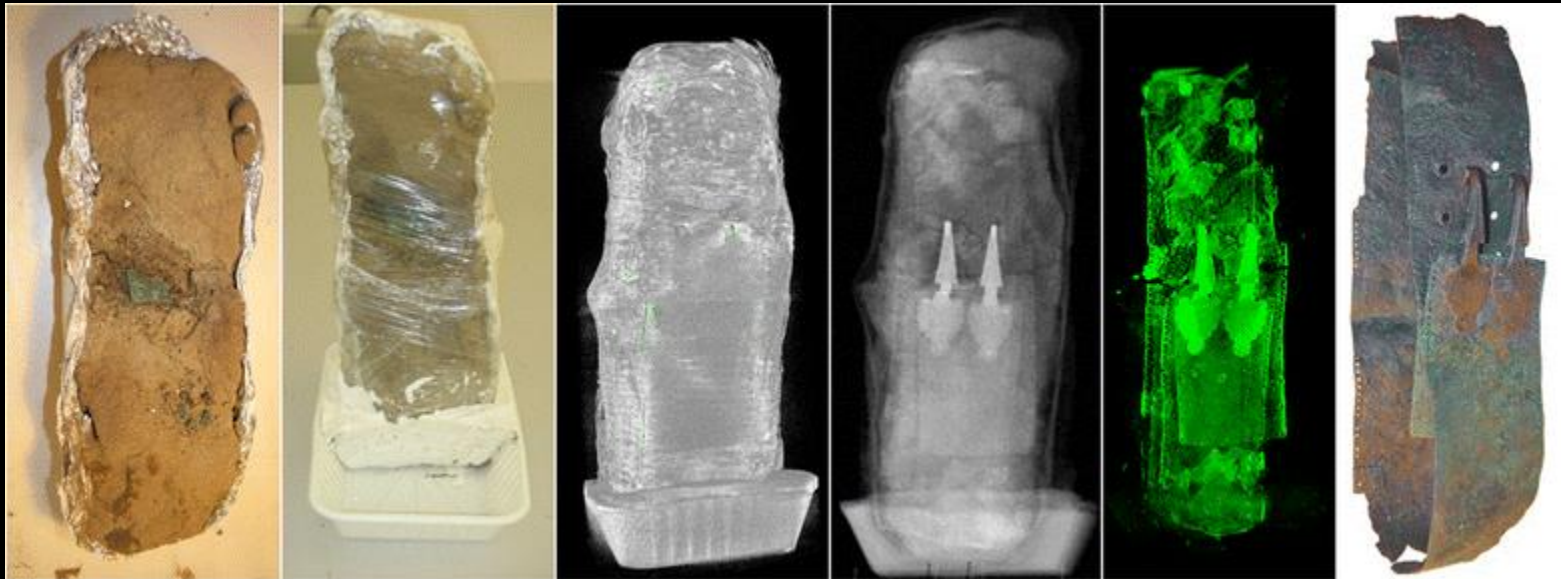
« Chamform »
(protection de la tête de cheval
avec une partie de la mâchoire)

Documentation en 3D

Tomodensitométrie (Computed Tomography - CT)

⇒ Quelques exemples

Analyses des objets *In situ*



Un block contenant une ceinture (6-4 s. BC)

Documentation en 3D

Tomodensitométrie (Computed Tomography - CT)

⇒ Quelques exemples

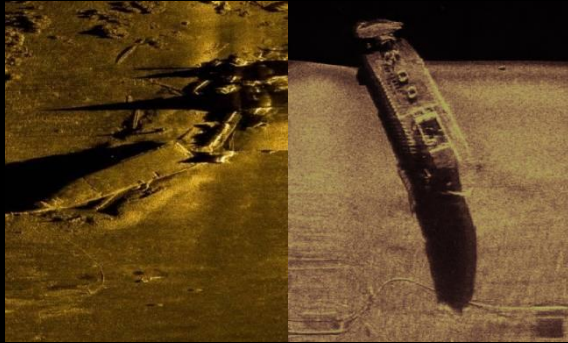
Potentiel énorme ...



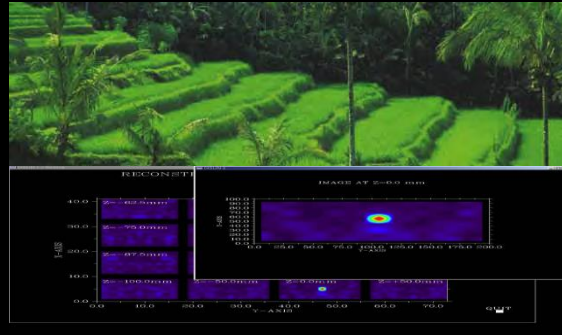
Documentation en 3D

Méthodes moins conventionnelles

Sonar



Micro-ondes



IR



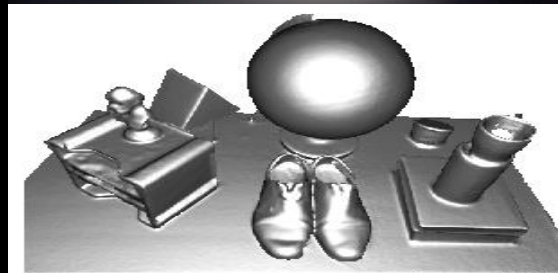
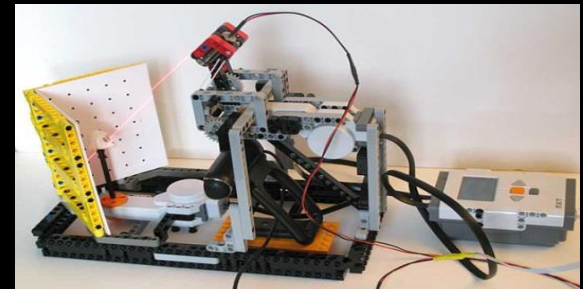
Ultrason



Kinect

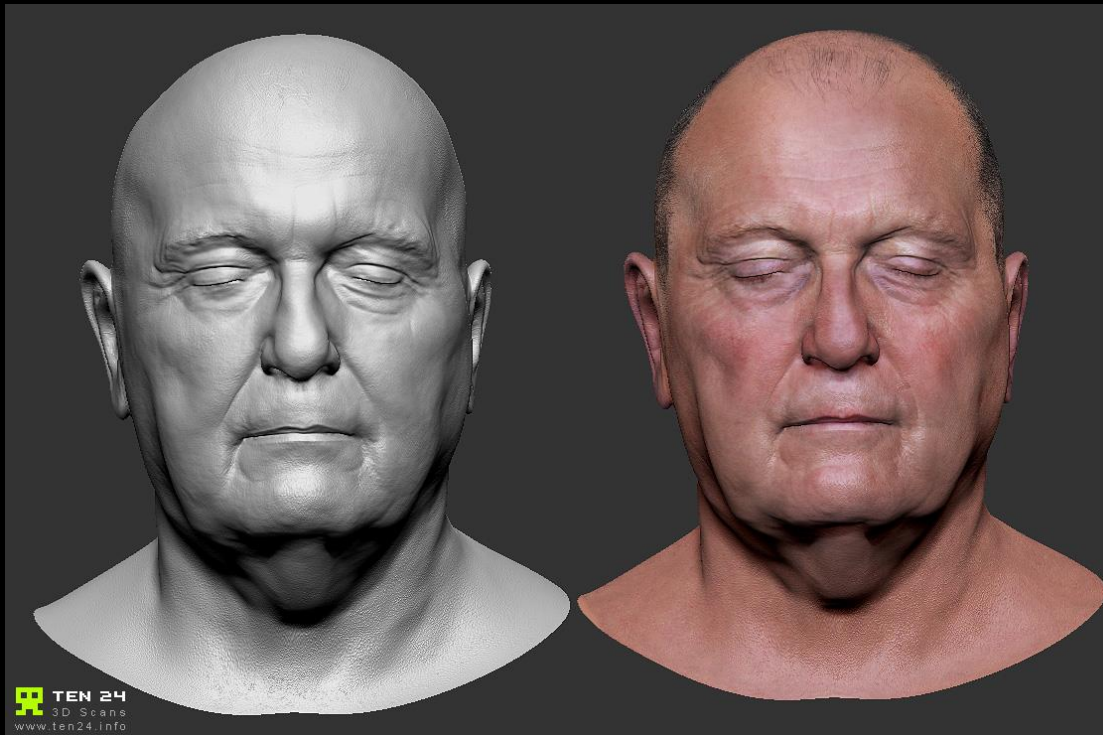


Lego 3D scanner et DIY



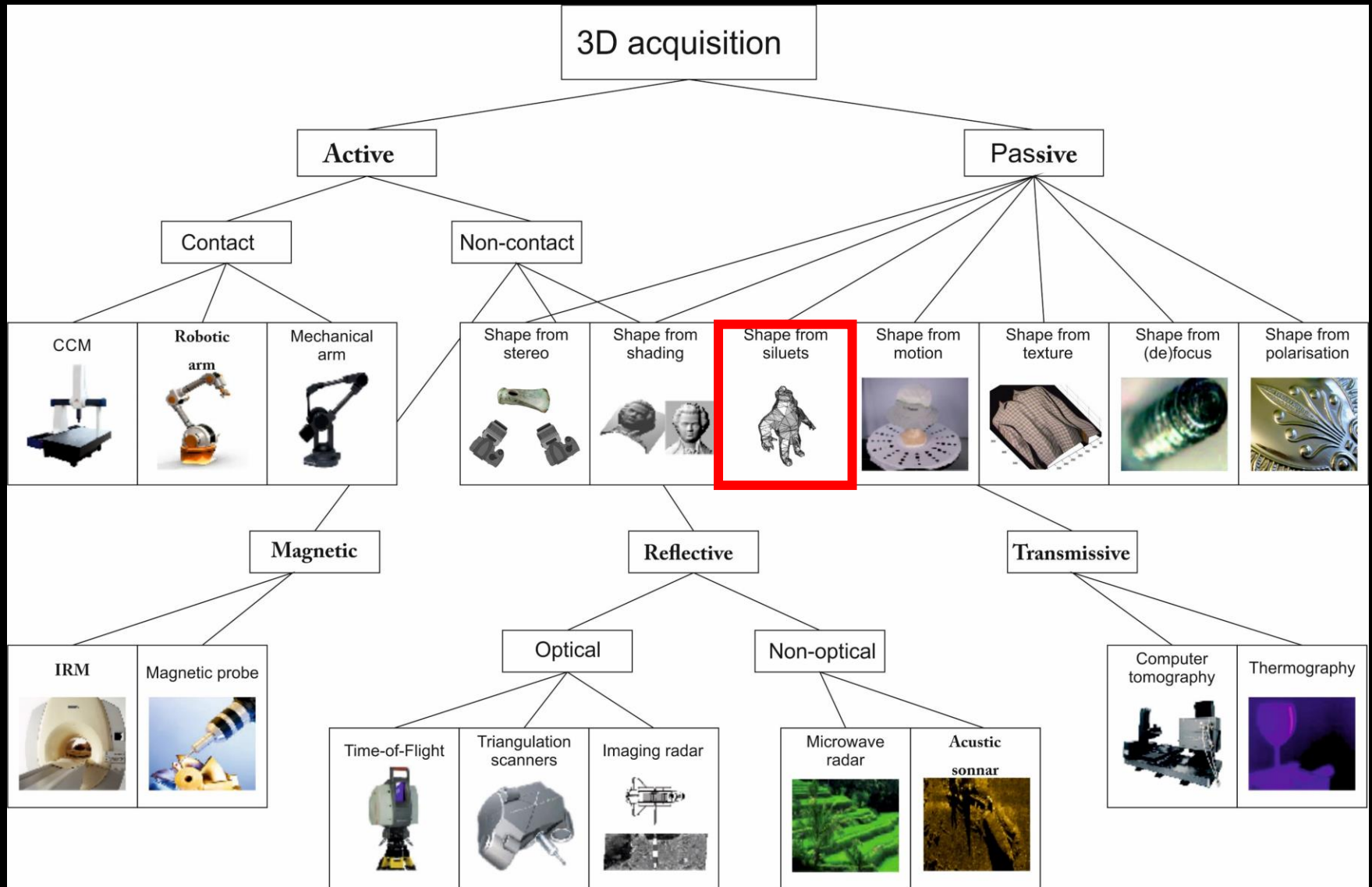
Méthodes moins conventionnelles

Vectra (2011)



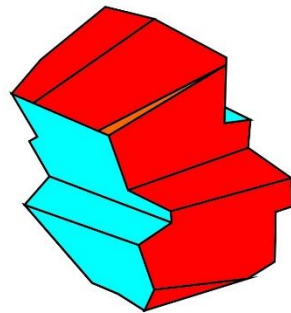
Documentation en 3D

Quelles technologies peut-on utiliser pour faire la 3D ?



Shape from Siluets

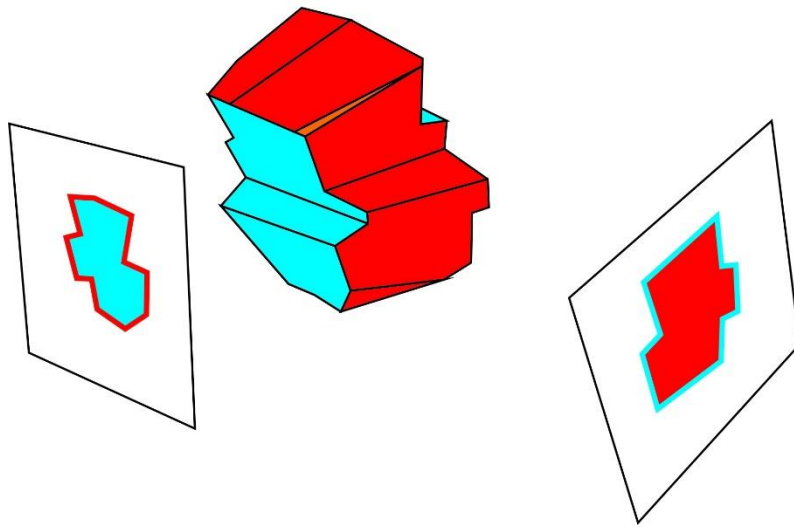
⇒ Comment ça marche ?



Documentation en 3D

Shape from Siluets

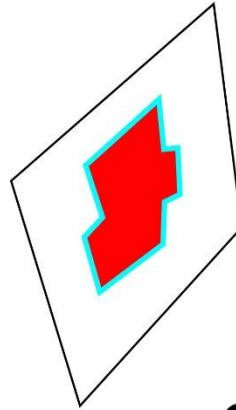
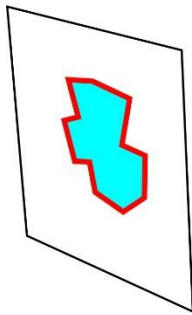
⇒ Comment ça marche ?



Documentation en 3D

Shape from Siluets

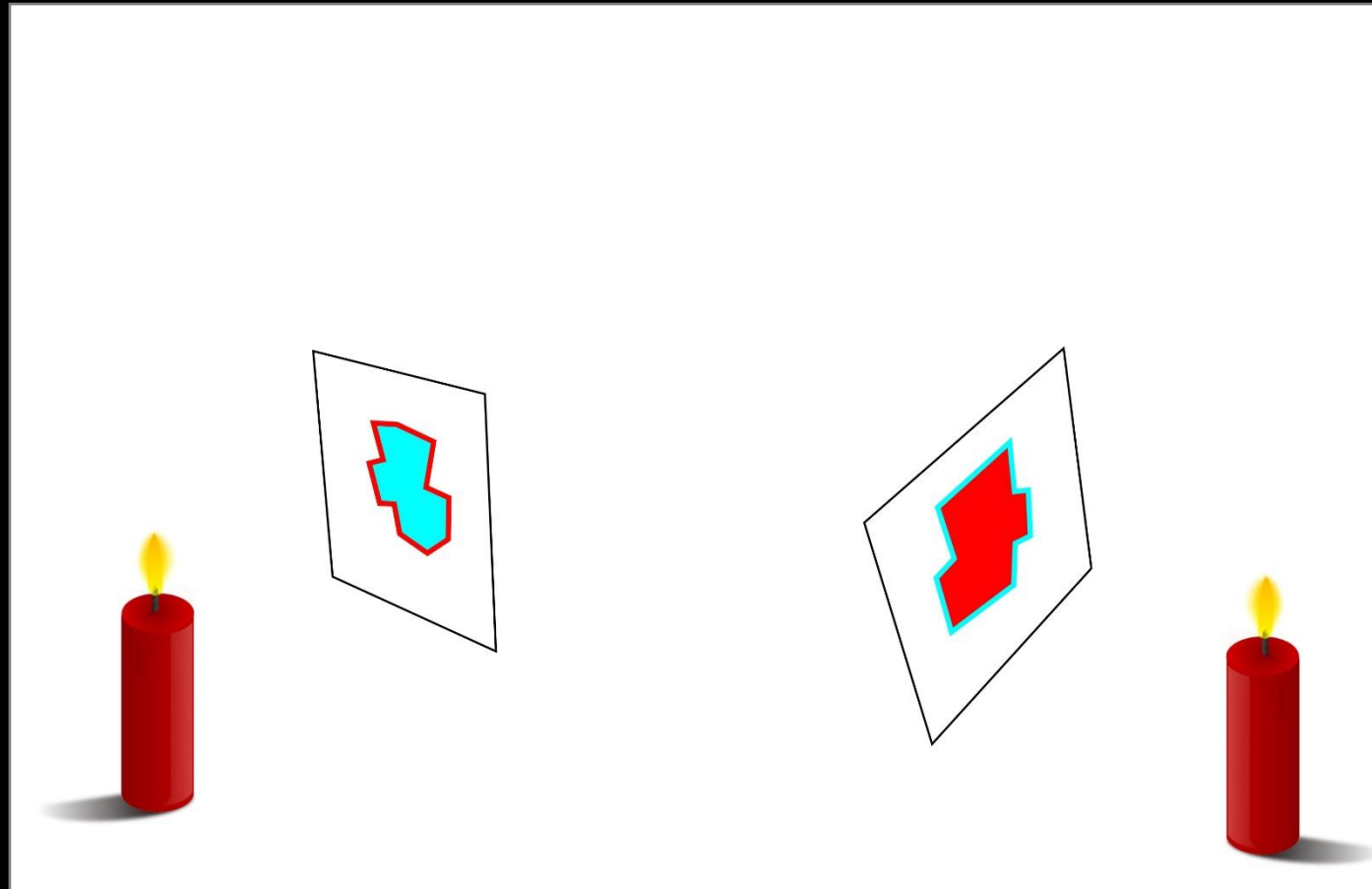
⇒ Comment ça marche ?



Documentation en 3D

Shape from Siluets

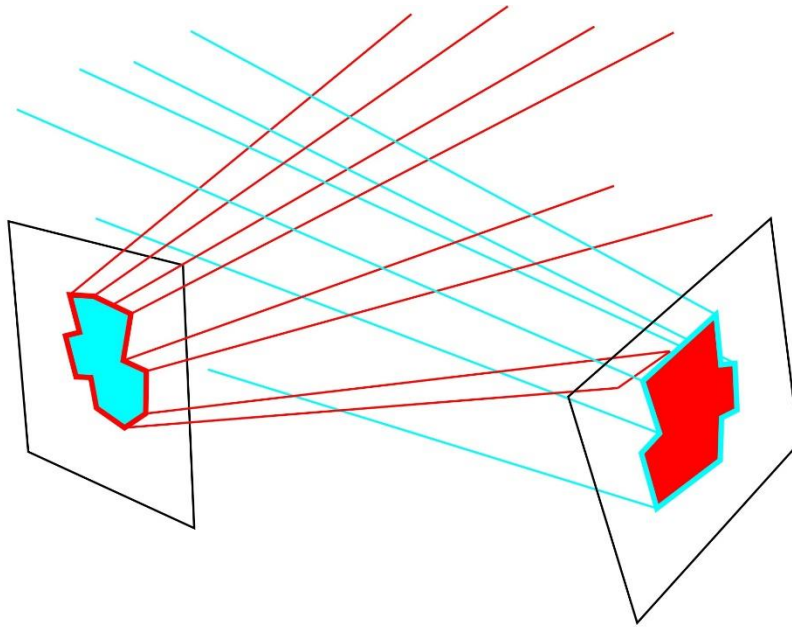
⇒ Comment ça marche ?



Documentation en 3D

Shape from Siluets

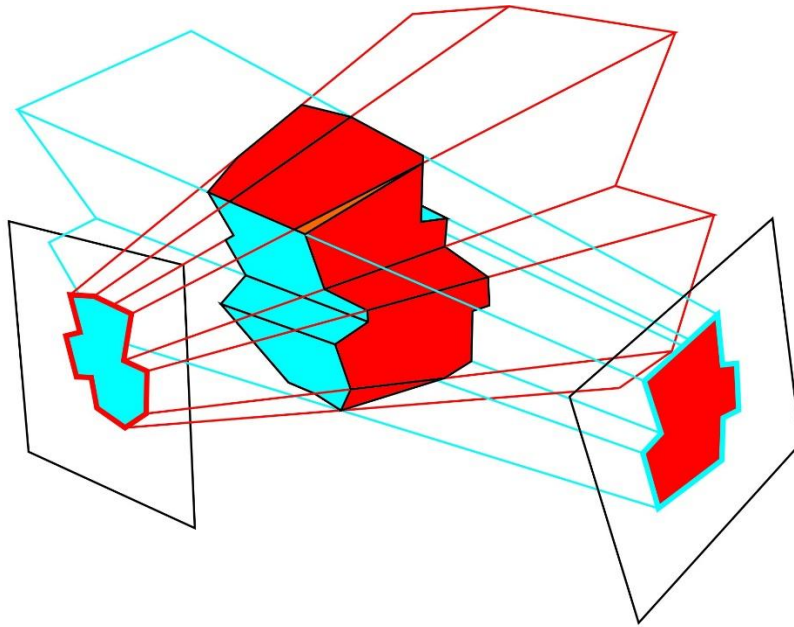
⇒ Comment ça marche ?



Documentation en 3D

Shape from Siluets

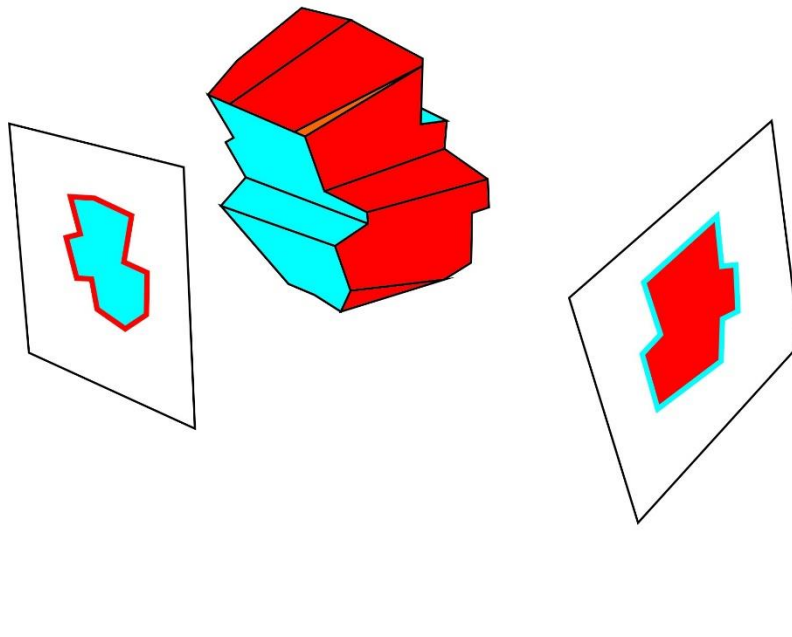
⇒ Comment ça marche ?



Documentation en 3D

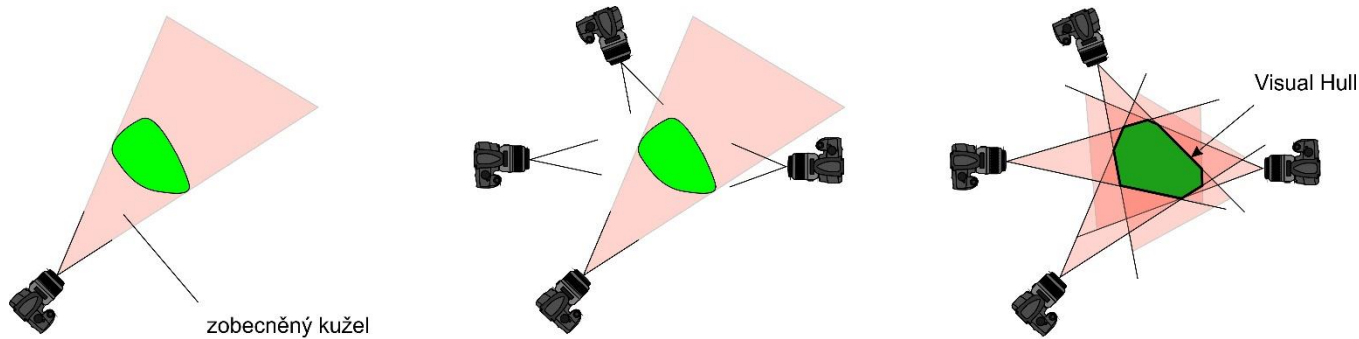
Shape from Siluets

⇒ Comment ça marche ?



Shape from Siluets

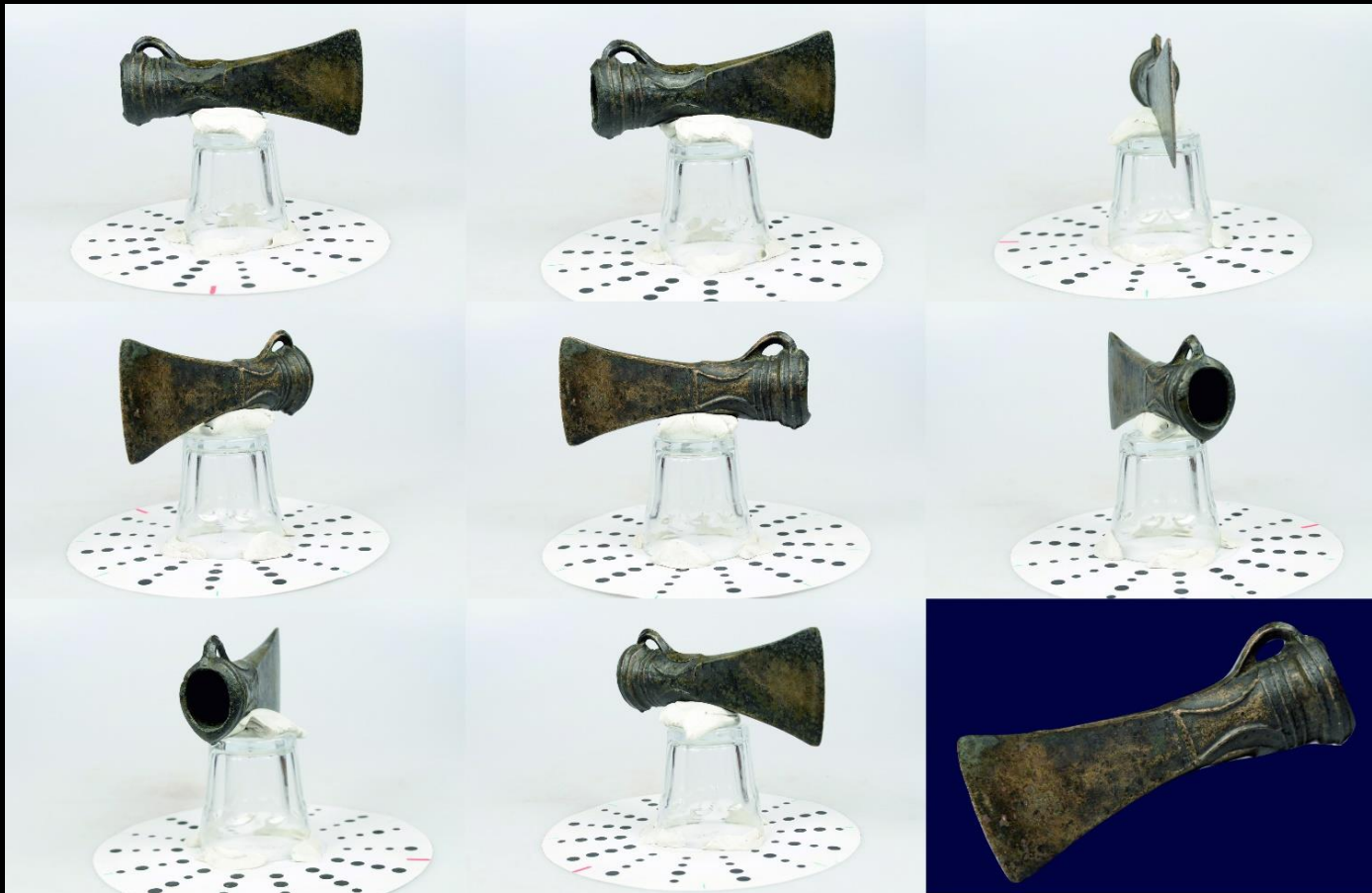
⇒ Comment ça marche ?



Documentation en 3D

Shape from Siluets

⇒ Comment faire une acquisition et traitement de données ?



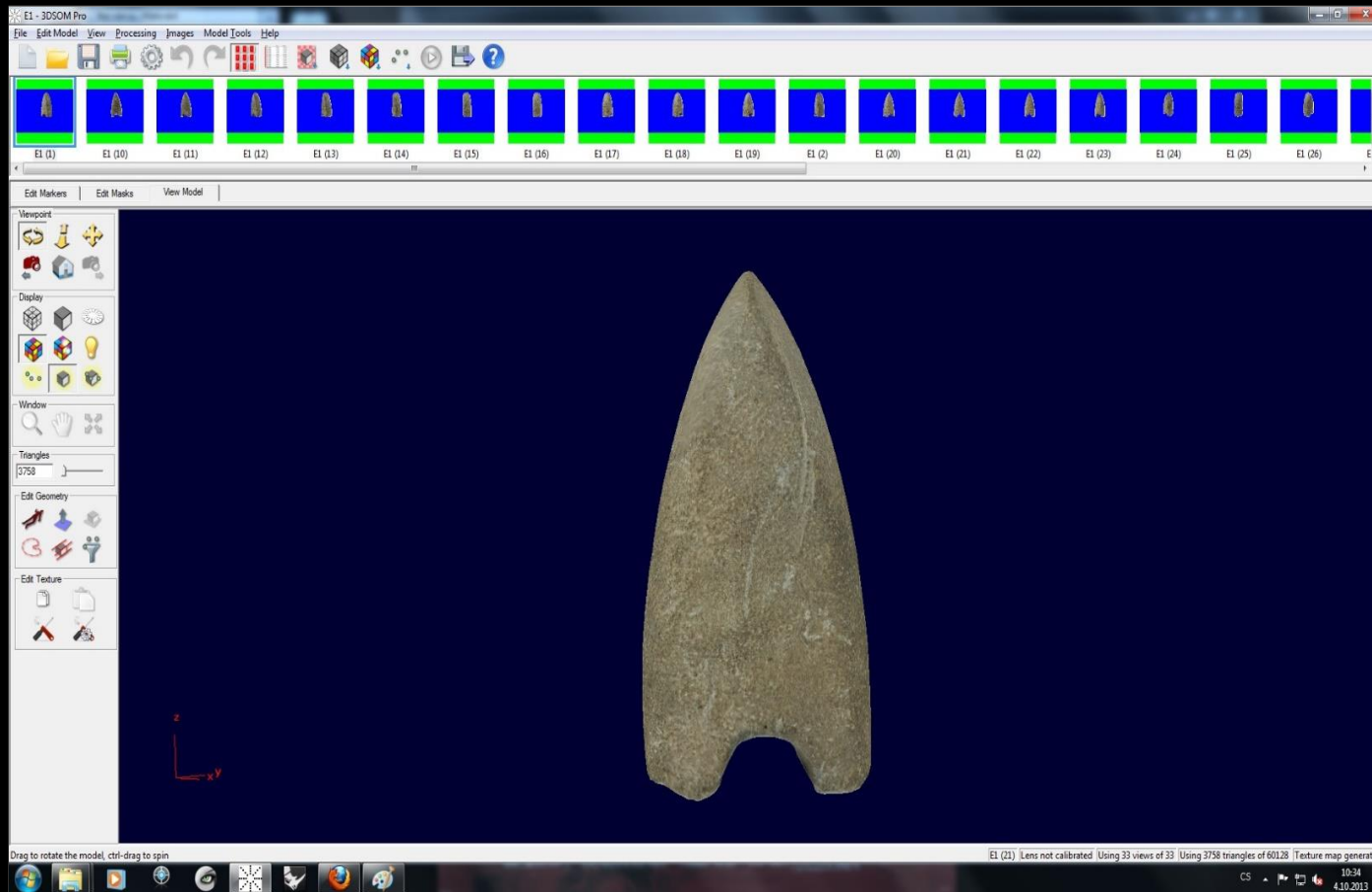
Calibration

Documentation en 3D

Shape from Siluets

⇒ Comment faire une acquisition et traitement de données ?

3D SOM

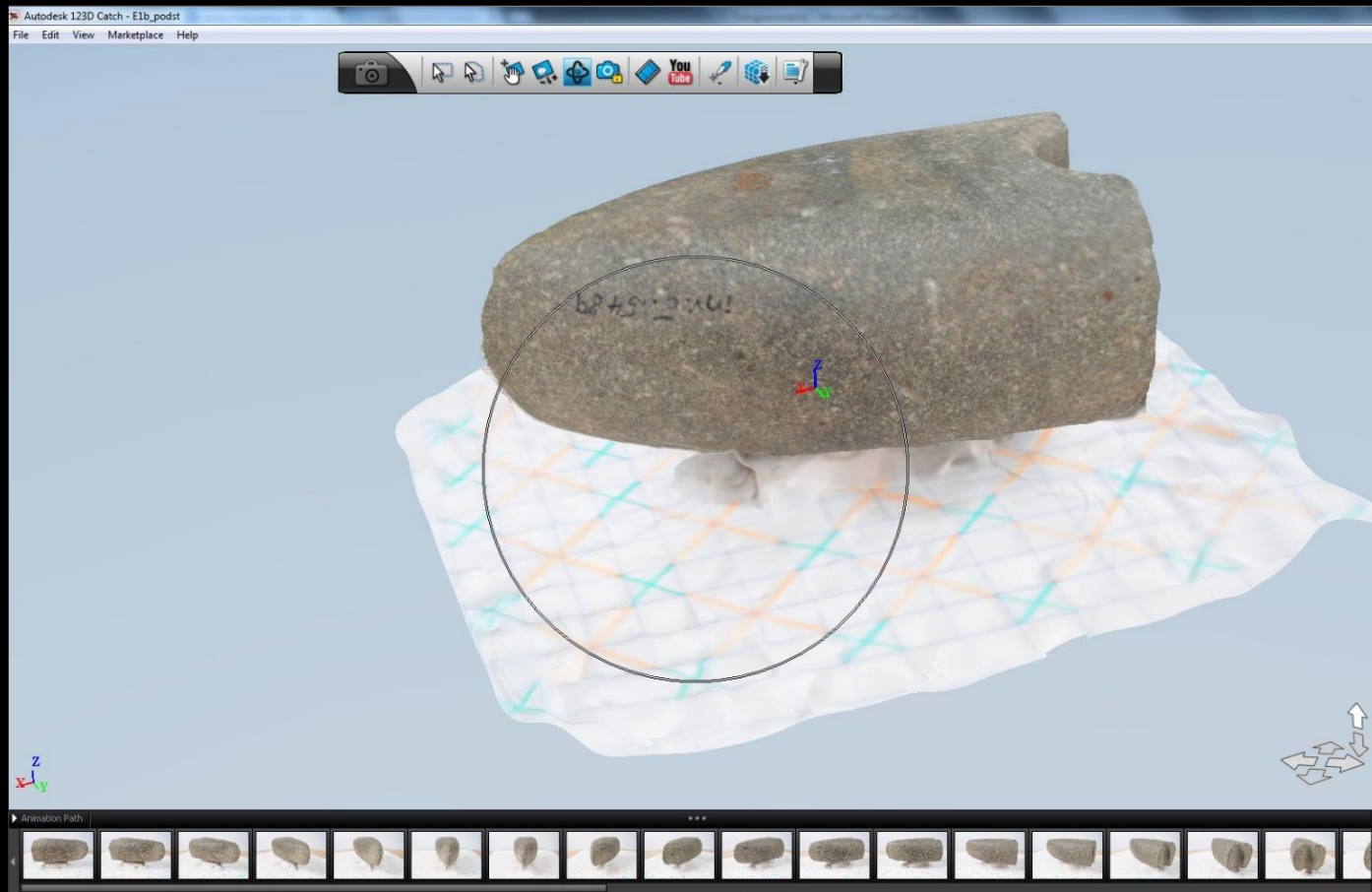


Documentation en 3D

Shape from Siluets

⇒ Comment faire une acquisition et traitement de données ?

Autodesk 123D Catch

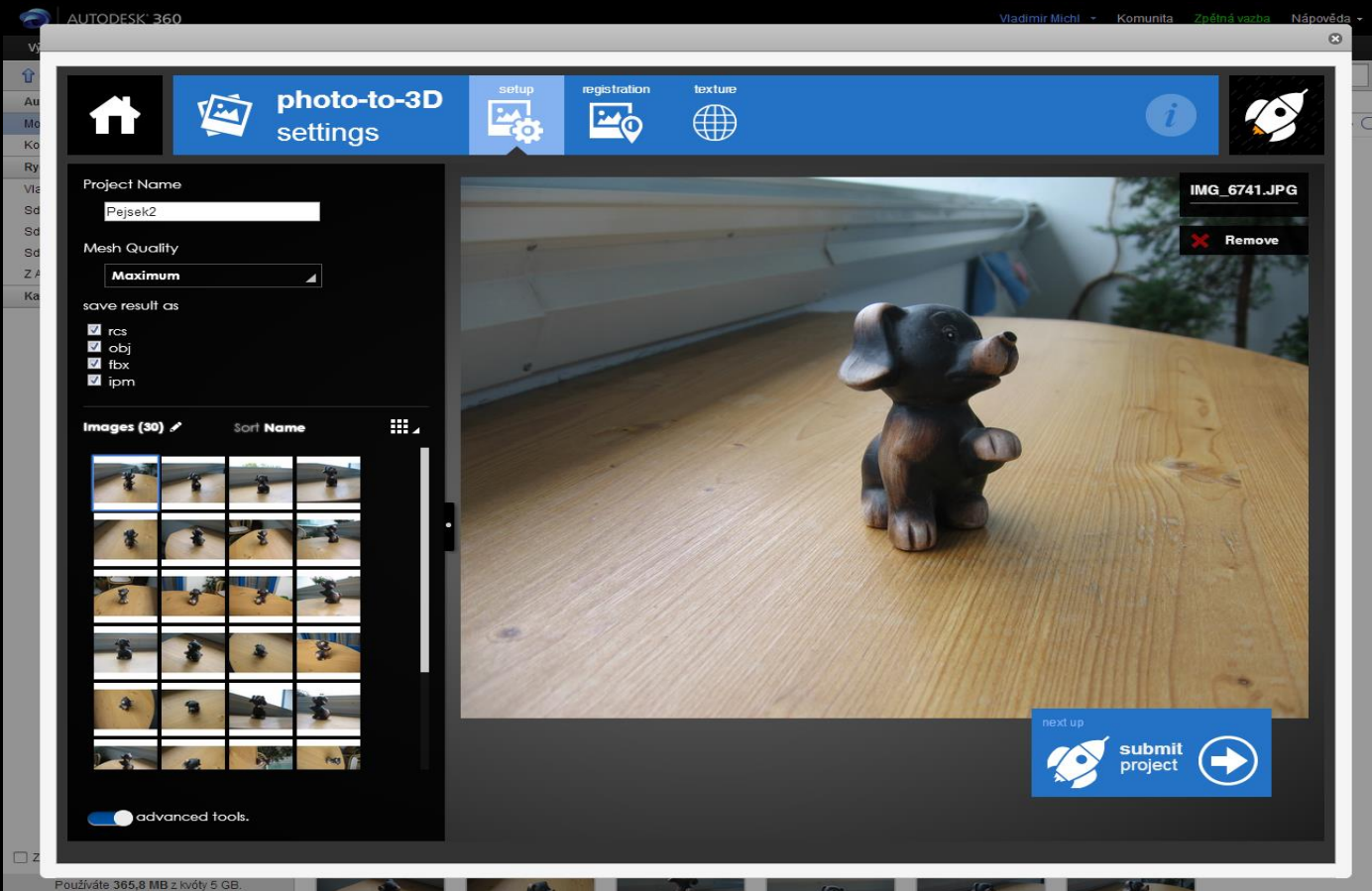


Documentation en 3D

Shape from Siluets

⇒ Comment faire une acquisition et traitement de données ?

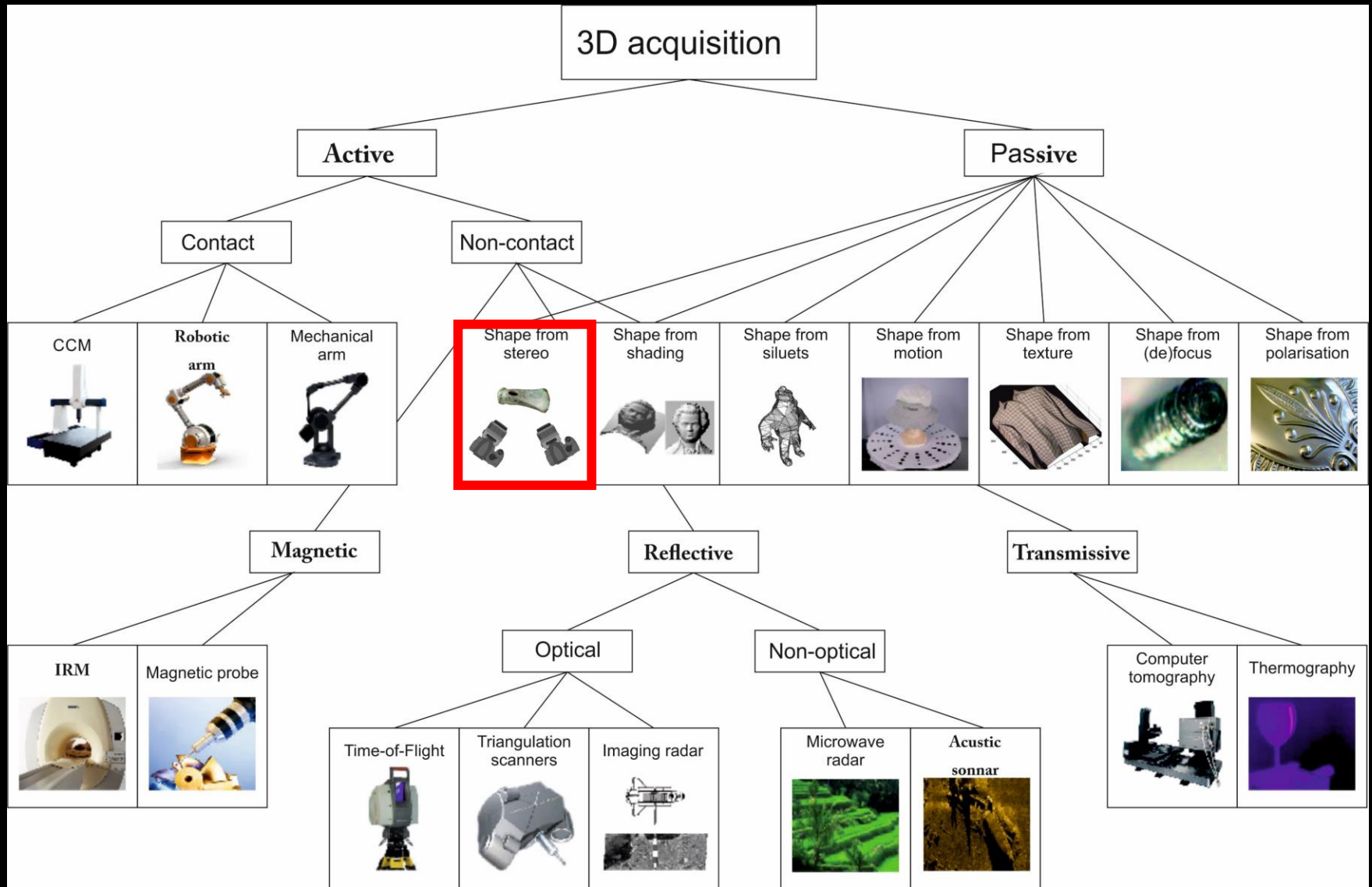
Autodesk® ReCap™



Nouvelle version
(utilise plutôt Shape From Motion)

Documentation en 3D

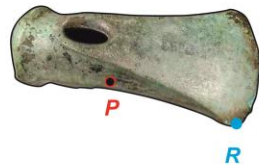
Quelles technologies peut-on utiliser pour faire la 3D ?



Documentation en 3D

Shape from Stereo

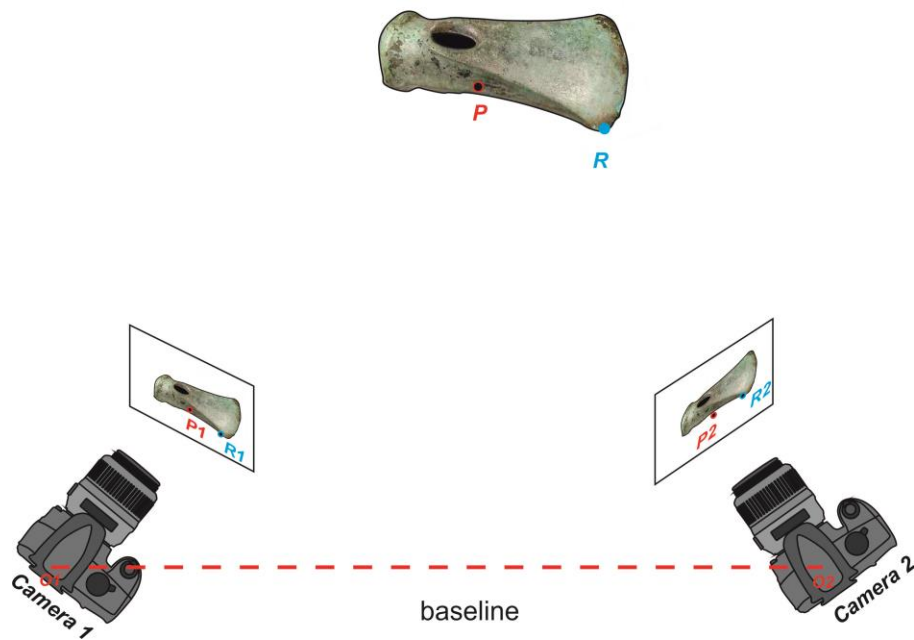
⇒ Comment ça marche ?



Documentation en 3D

Shape from Stereo

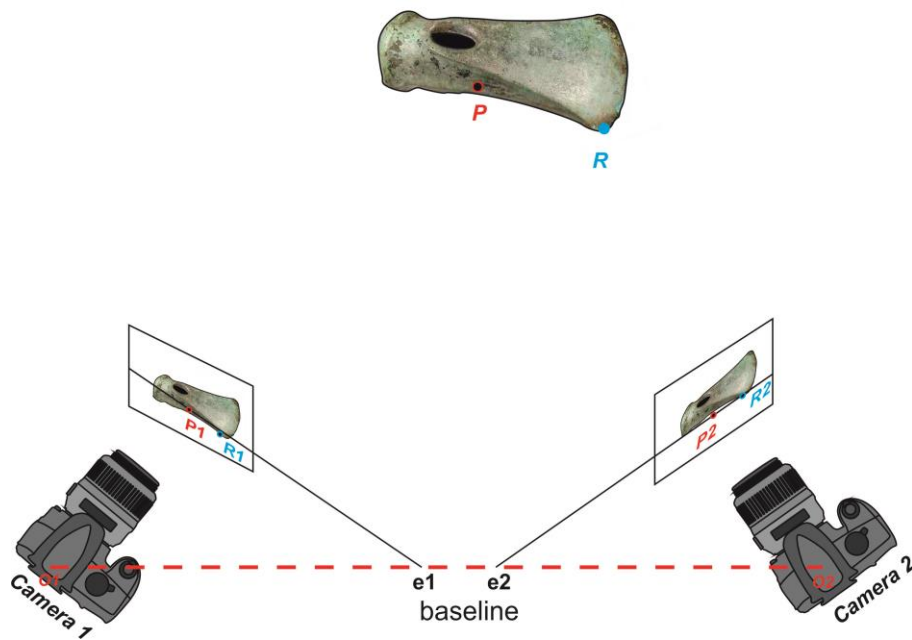
⇒ Comment ça marche ?



Documentation en 3D

Shape from Stereo

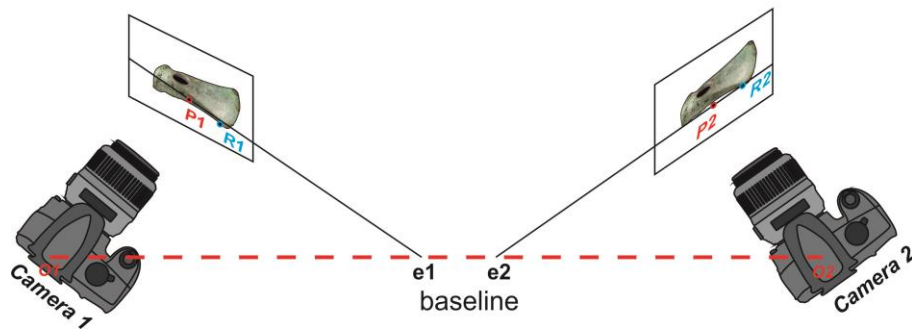
⇒ Comment ça marche ?



Documentation en 3D

Shape from Stereo

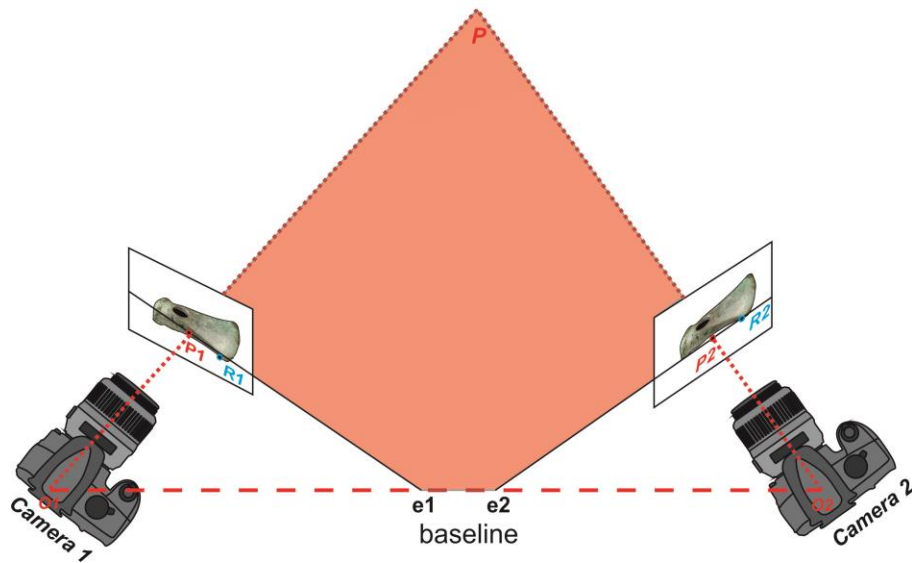
⇒ Comment ça marche ?



Documentation en 3D

Shape from Stereo

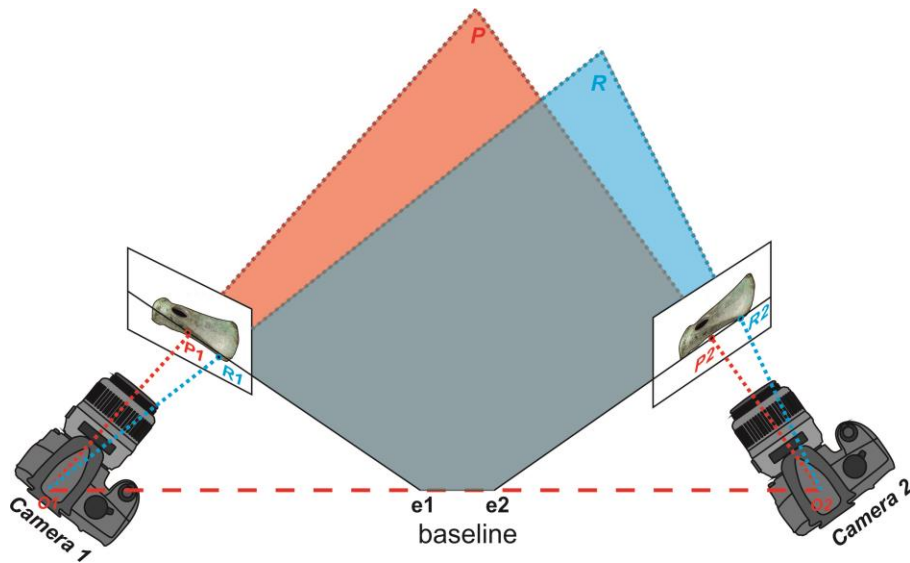
⇒ Comment ça marche ?



Documentation en 3D

Shape from Stereo

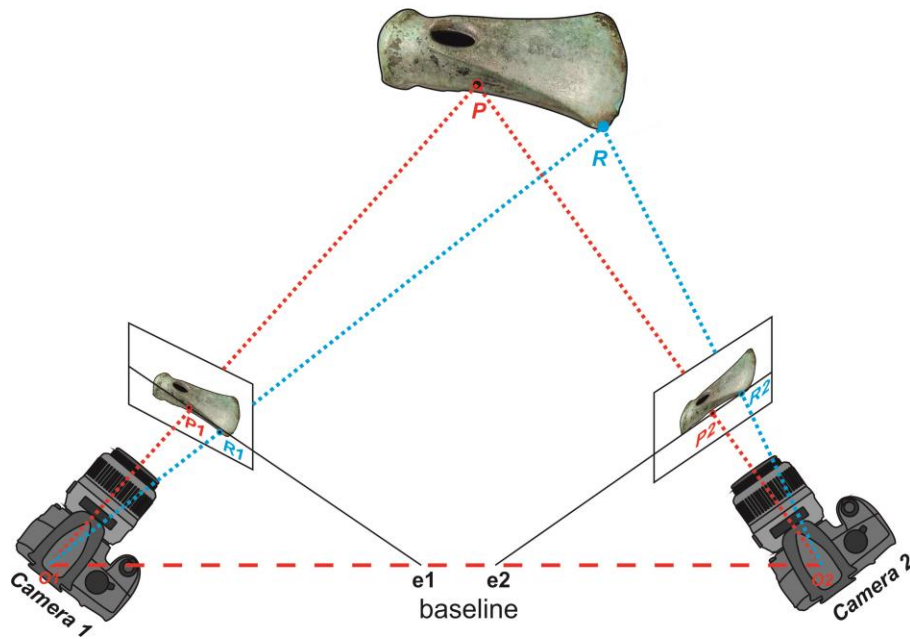
⇒ Comment ça marche ?



Documentation en 3D

Shape from Stereo

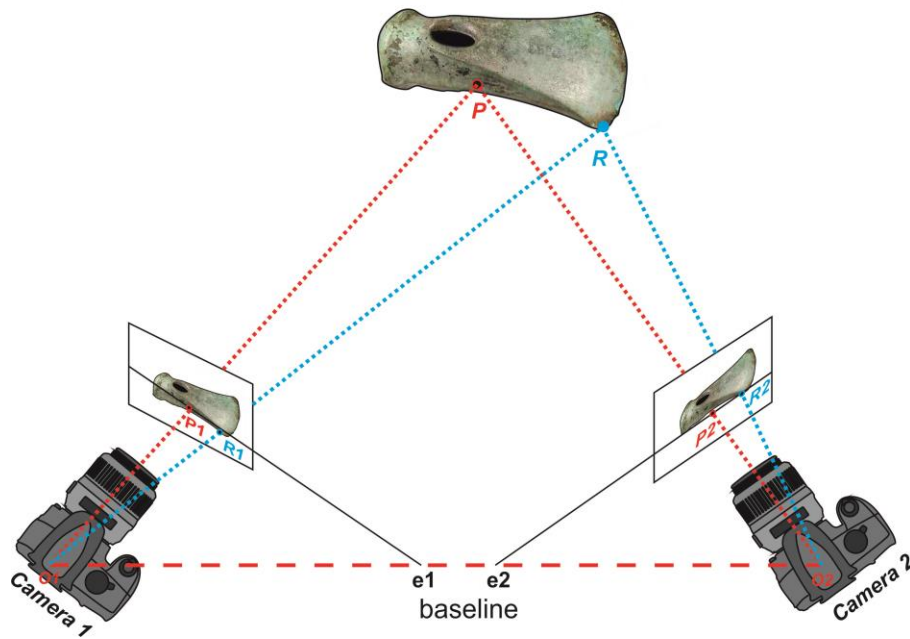
⇒ Comment ça marche ?



Documentation en 3D

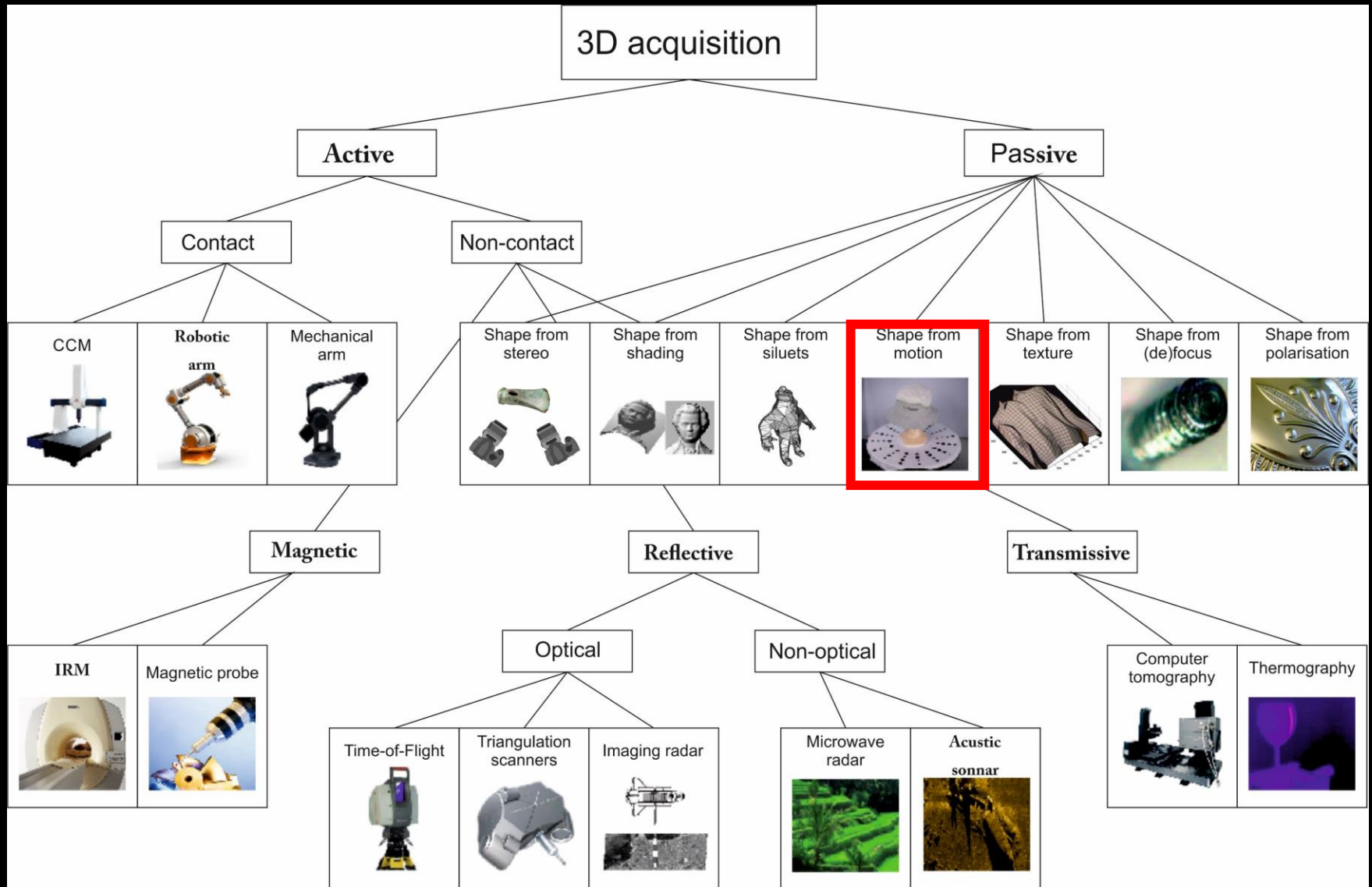
Shape from Stereo

⇒ Comment ça marche ?



Documentation en 3D

Quelles technologies peut-on utiliser pour faire la 3D ?



Documentation en 3D

Shape from Motion

⇒ Comment ça marche ?



Documentation en 3D

Shape from Motion

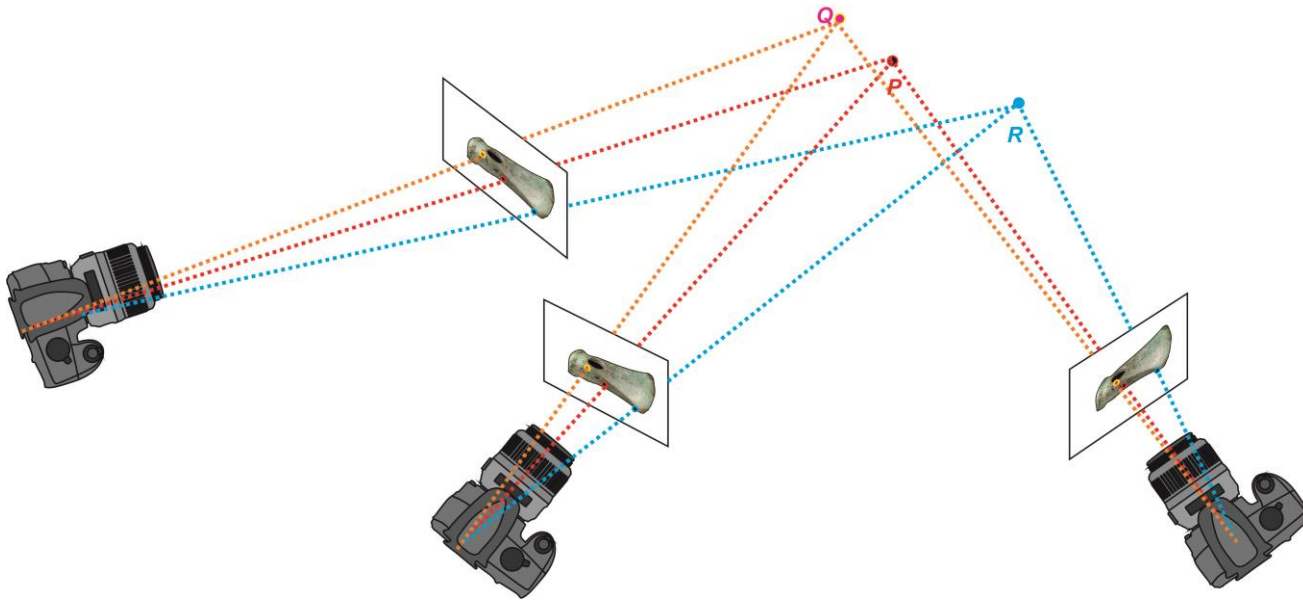
⇒ Comment ça marche ?



Documentation en 3D

Shape from Motion

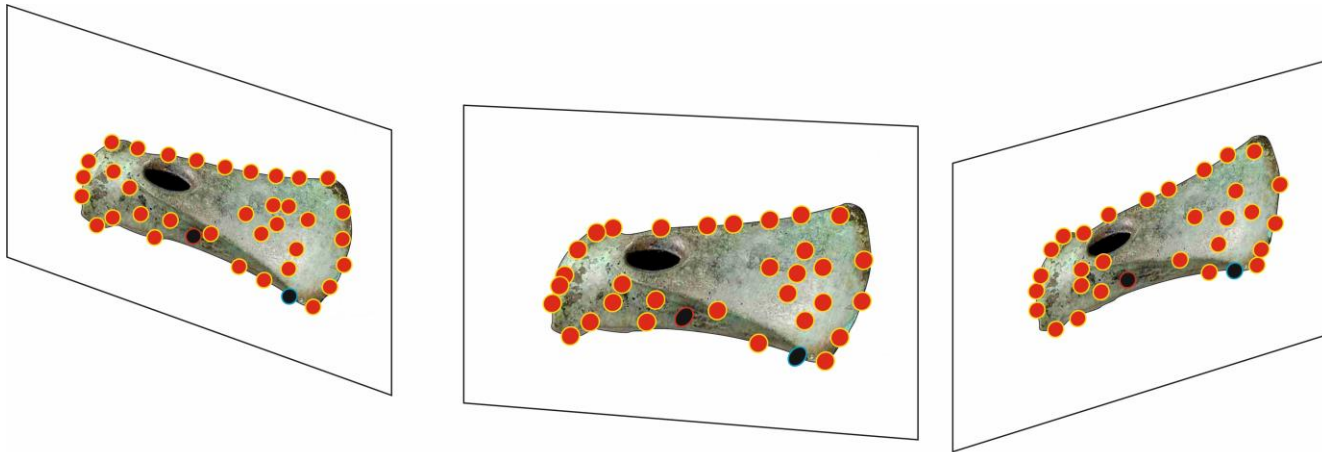
⇒ Comment ça marche ?



Documentation en 3D

Shape from Motion

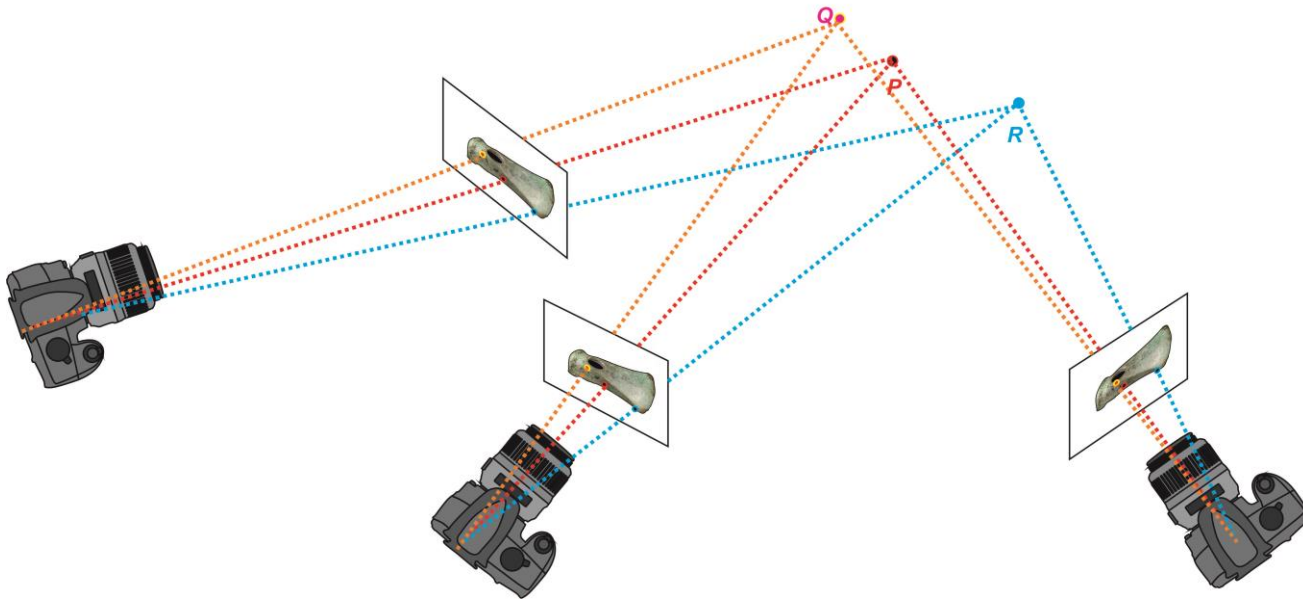
⇒ Comment ça marche ?



Documentation en 3D

Shape from Motion

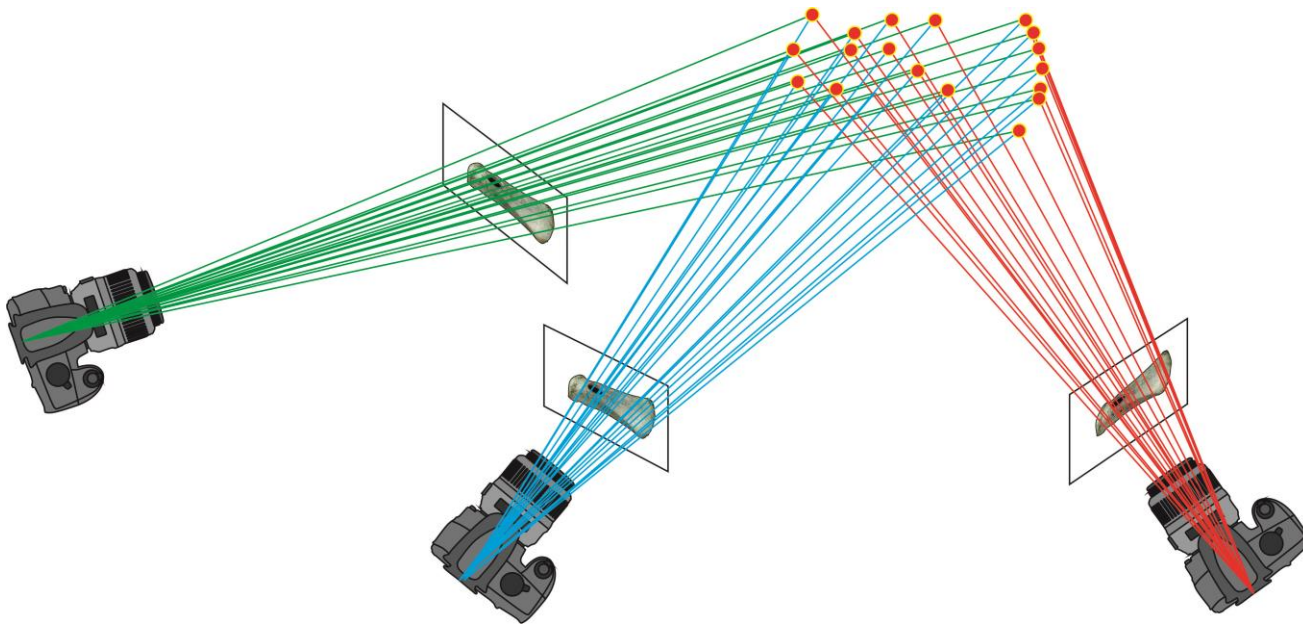
⇒ Comment ça marche ?



Documentation en 3D

Shape from Motion

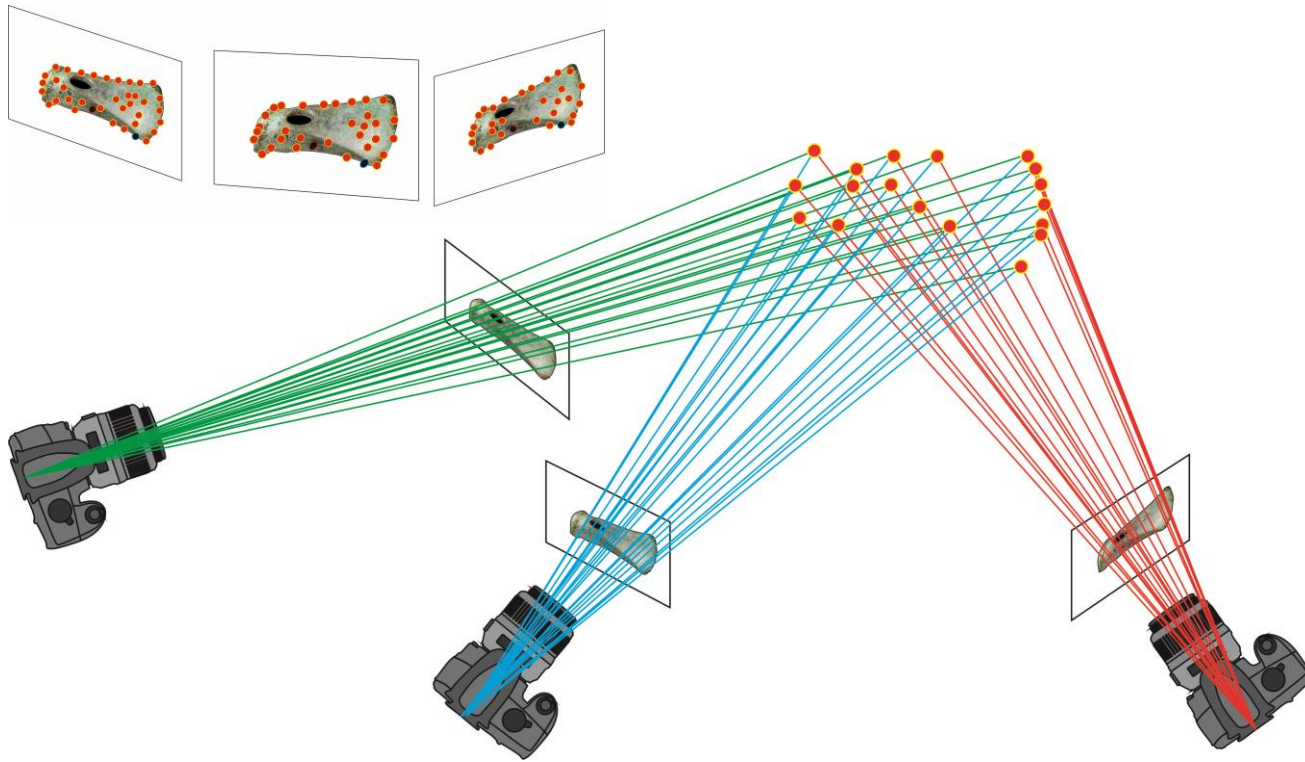
⇒ Comment ça marche ?



Documentation en 3D

Shape from Motion

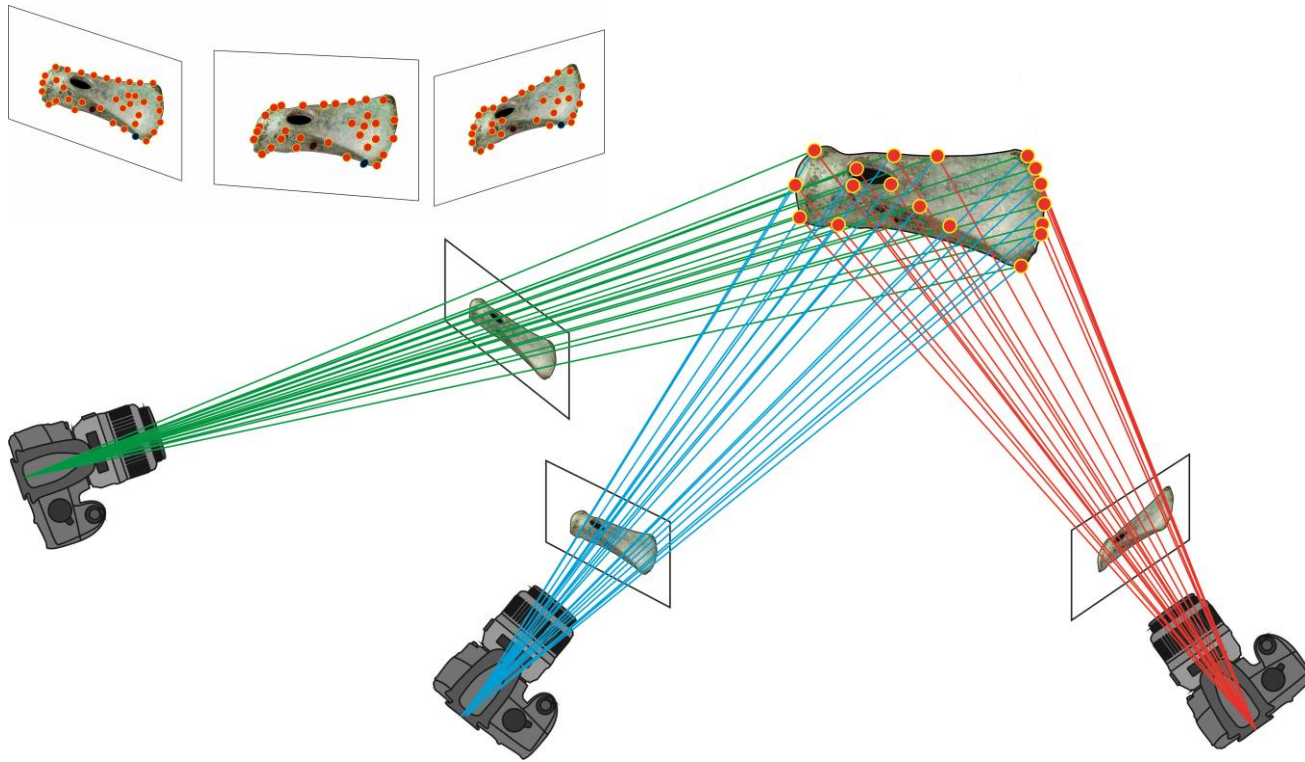
⇒ Comment ça marche ?



Documentation en 3D

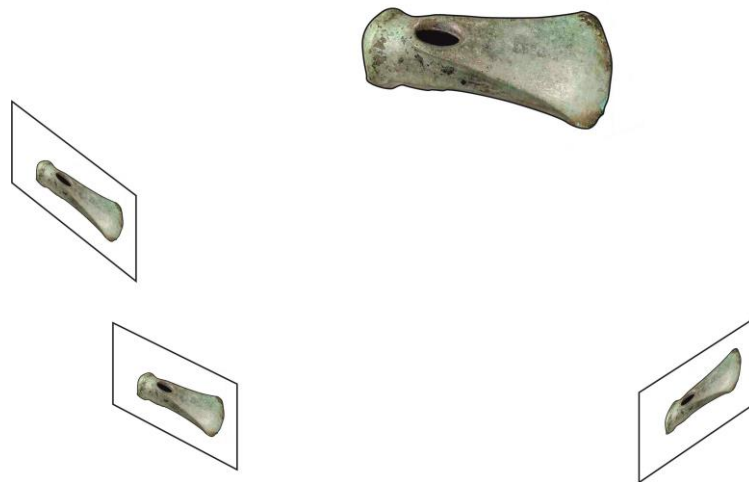
Shape from Motion

⇒ Comment ça marche ?



Shape from Motion

⇒ Comment ça marche ?

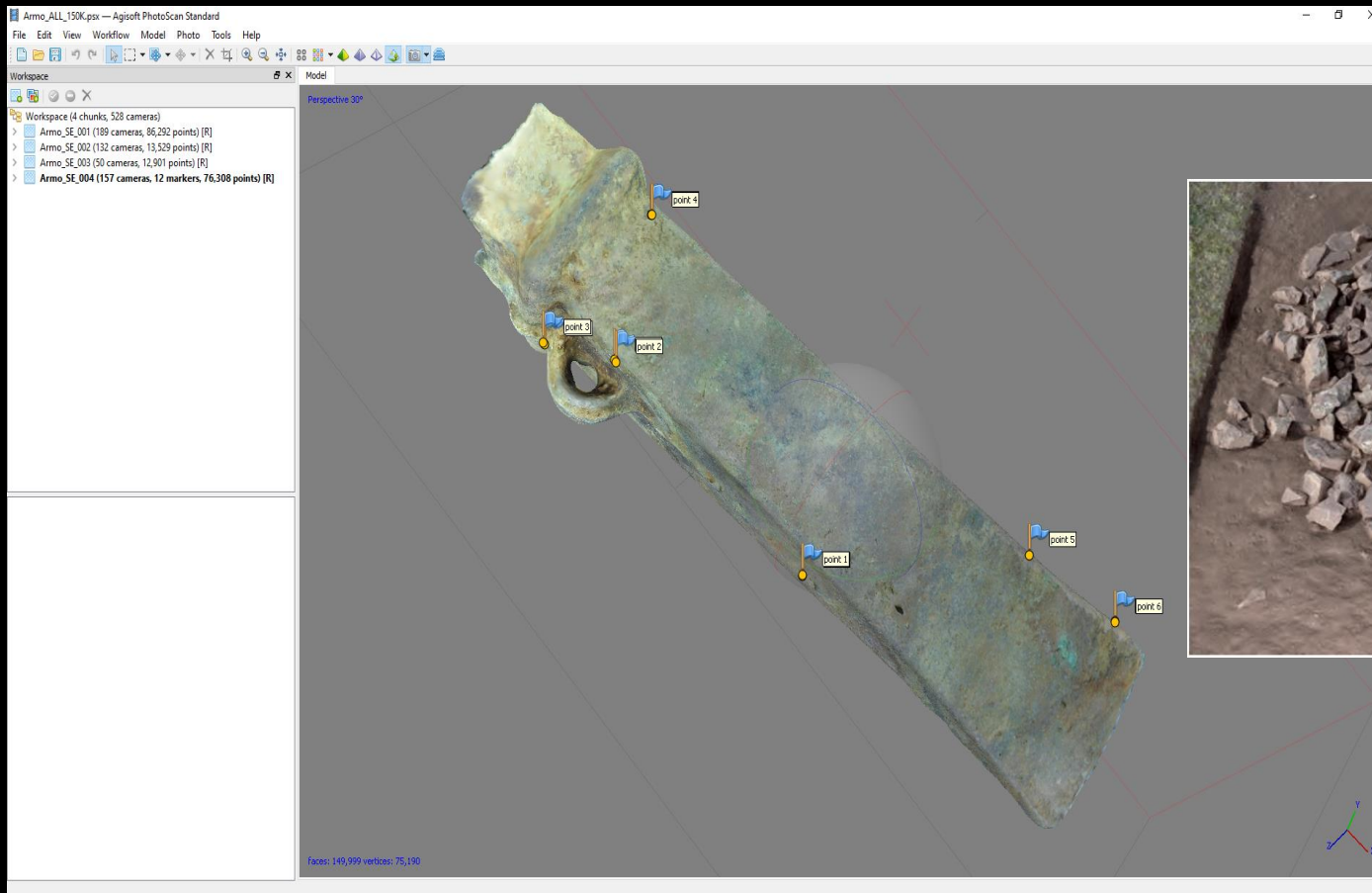


Documentation en 3D

Shape from Motion

⇒ Comment faire une acquisition et traitement de données ?

Agisoft Photoscan / Metashape

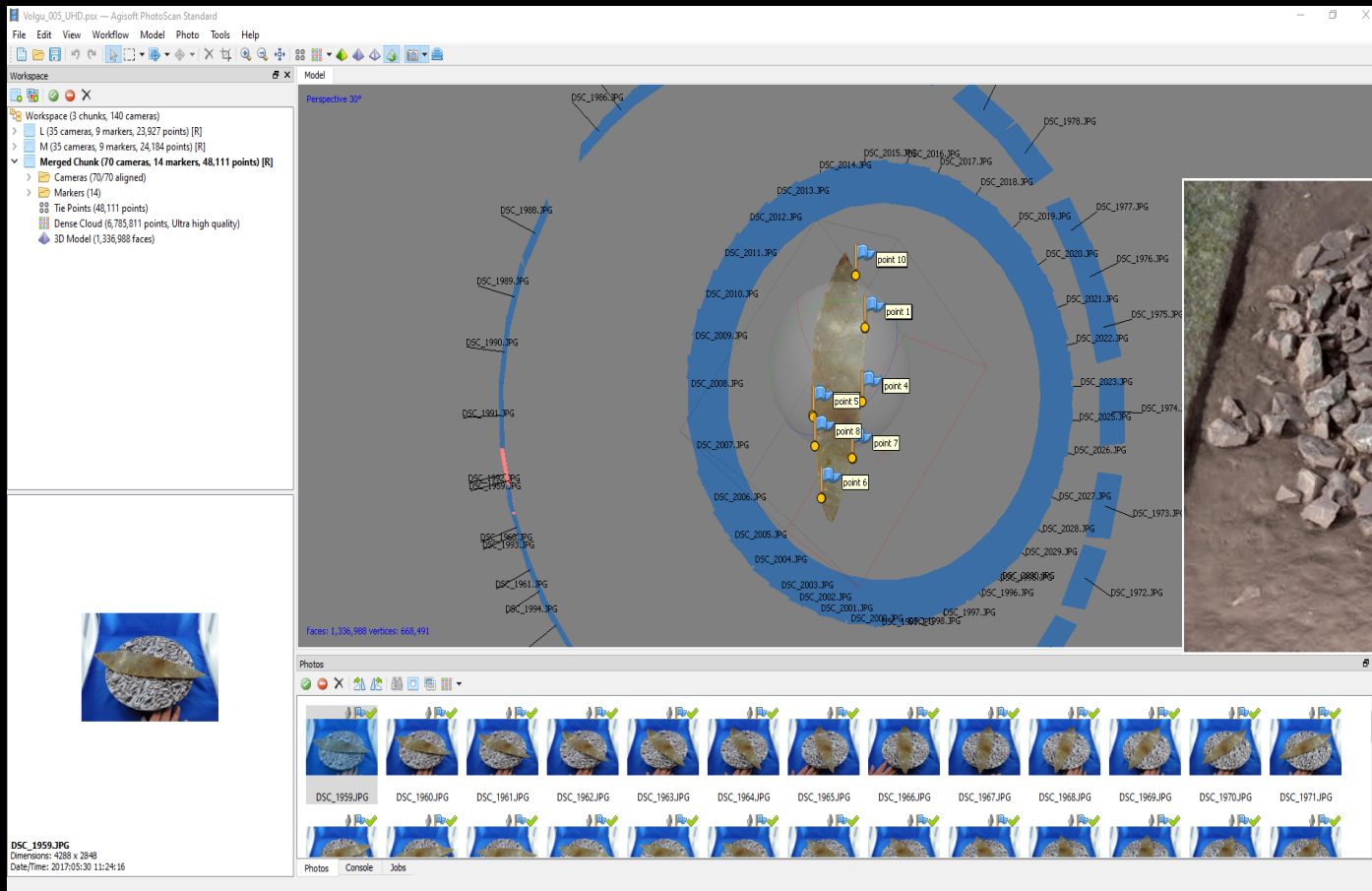


Documentation en 3D

Shape from Motion

⇒ Comment faire une acquisition et traitement de données ?

Agisoft Photoscan / Metashape



Documentation en 3D

Shape from Motion

⇒ Comment faire une acquisition et traitement de données ?

Micmac

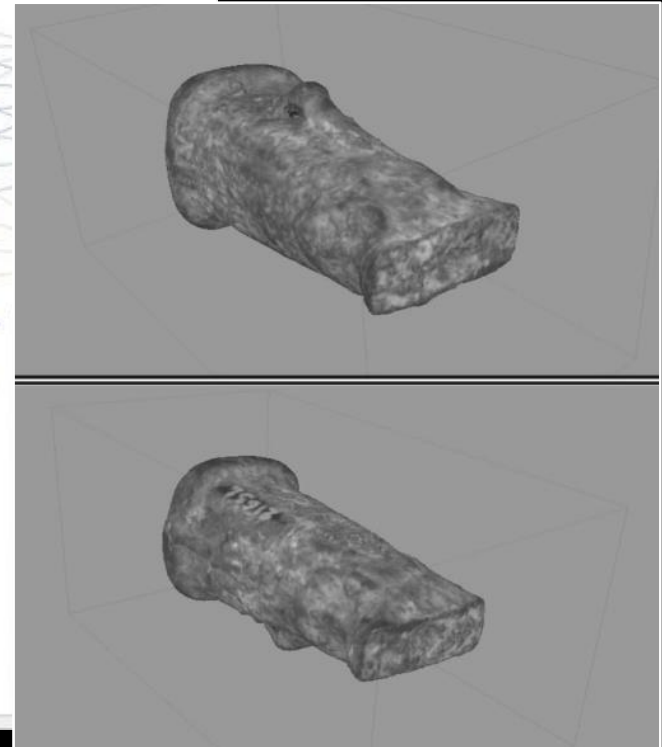
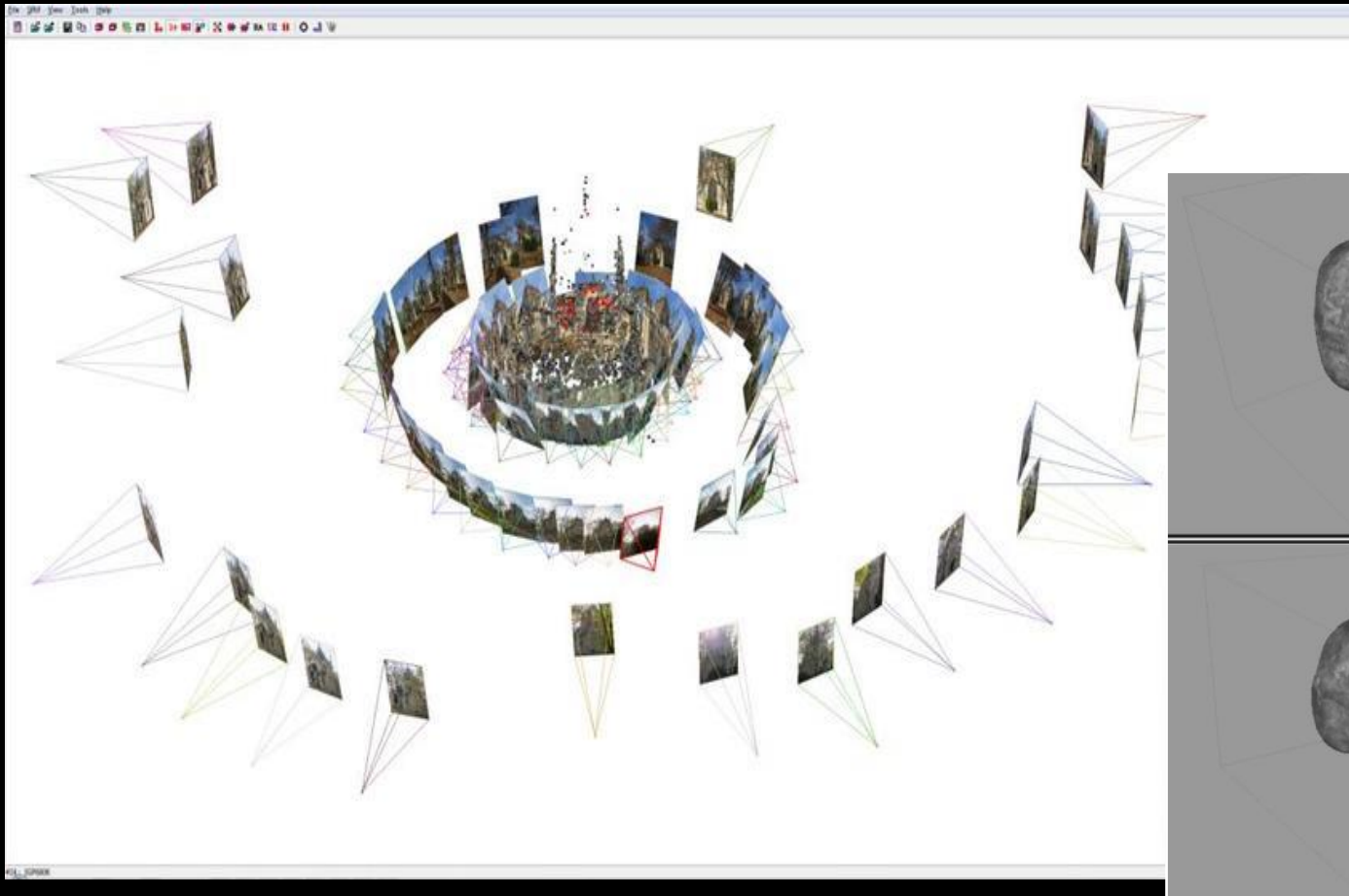


Documentation en 3D

Shape from Motion

⇒ Comment faire une acquisition et traitement de données ?

Visual SfM



Documentation en 3D

Quel type des données ?

Nuage de points

Maillage (Mesh)

Maillage (Mesh) avec texture

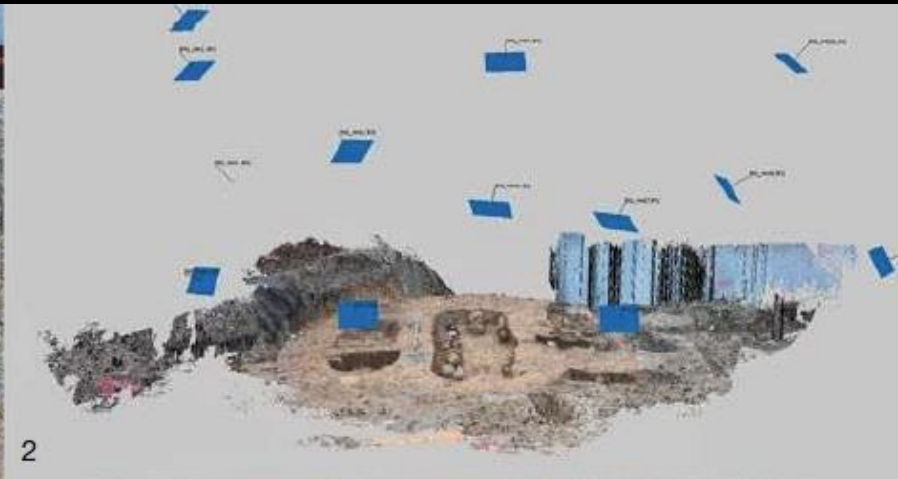


A quoi ça sert en archéologie et sur le terrain ?

Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Archivage, documentation, visualisation, reconstruction, présentation, ...



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

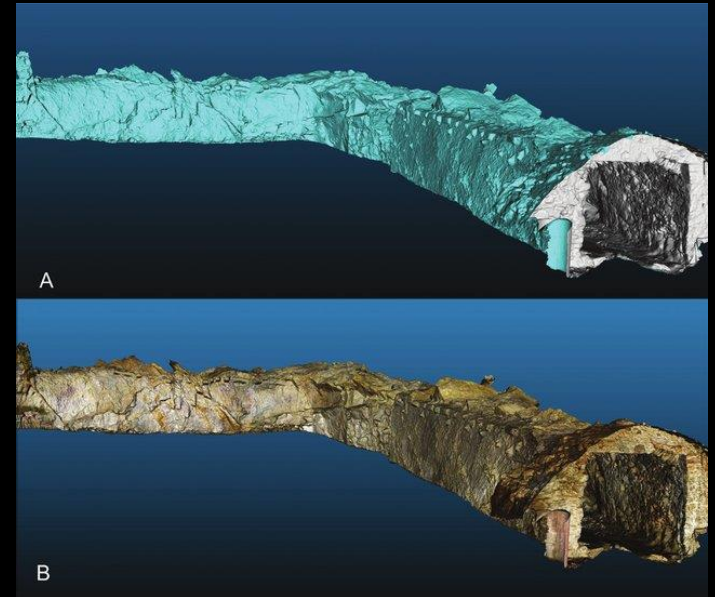
⇒ Archivage, documentation, visualisation, reconstruction, présentation, ...



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

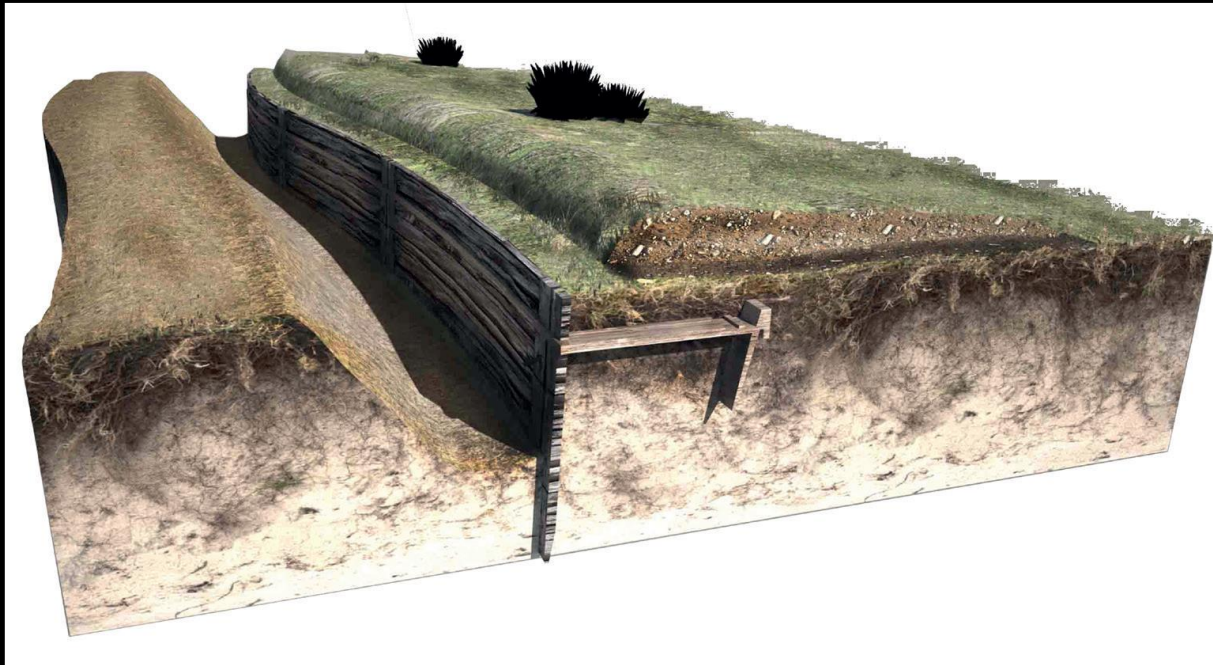
⇒ Archivage, documentation, visualisation, reconstruction, présentation, ...



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Archivage, documentation, visualisation, reconstruction, présentation, ...



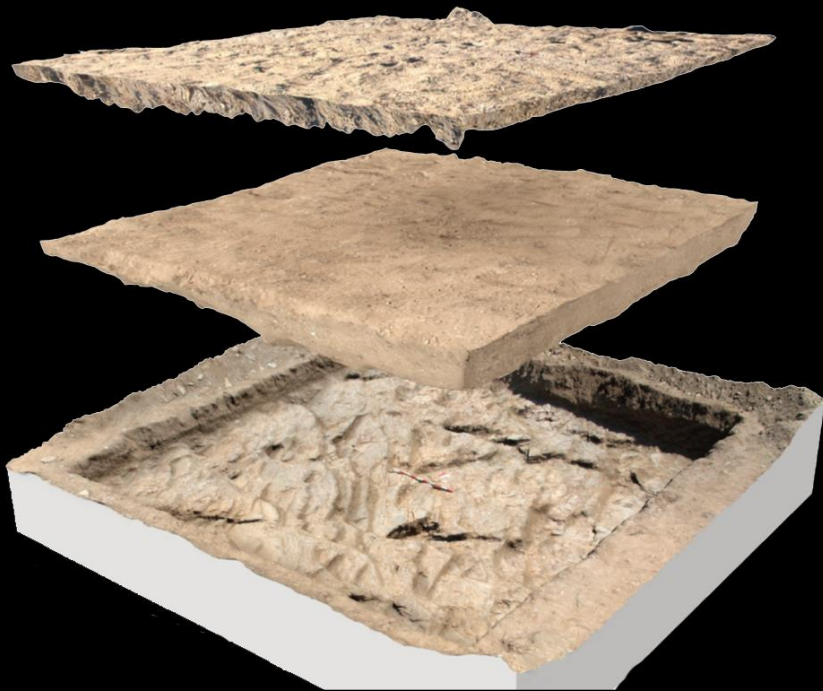
Modèle idéal d'un tranché Austro-Hongrois (1^{ère} guerre mondiale) crée a partir *Feldbefestigung und technischer Unterricht*.

Documentation en 3D

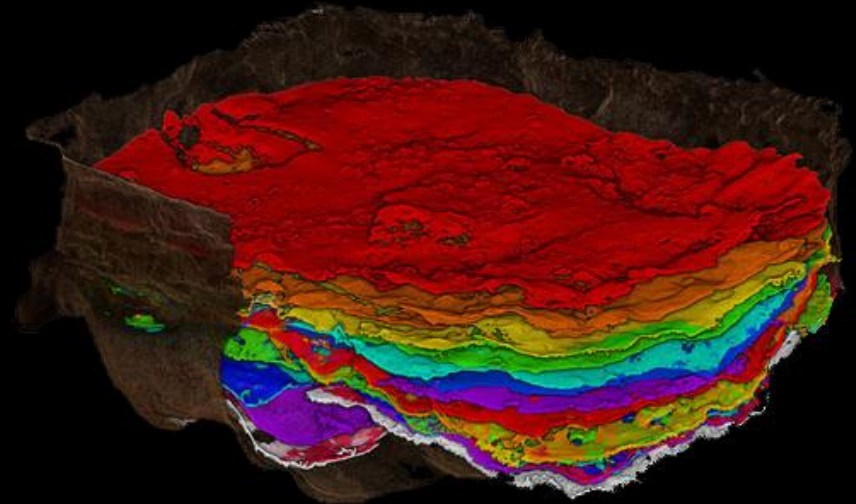
A quoi ça sert en archéologie et sur le terrain ?

⇒ Archivage, documentation, visualisation, reconstruction, présentation, ...

4D



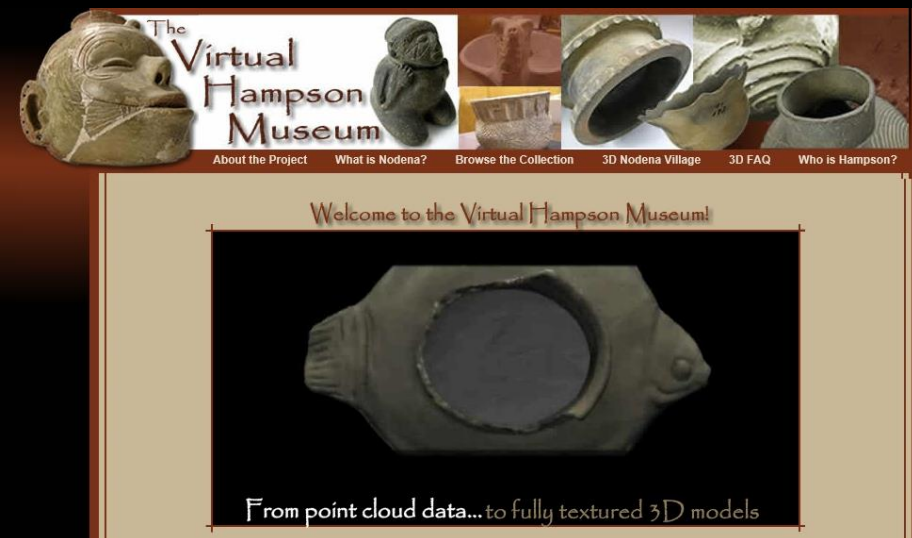
4D



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Musées virtuels / Visites virtuelles



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

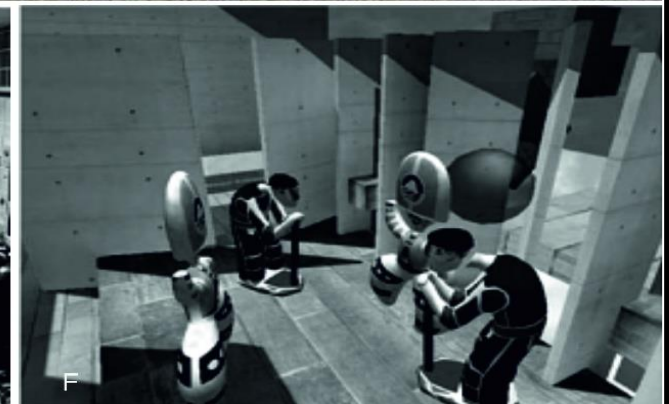
⇒ Musées virtuels / Visites virtuelles



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

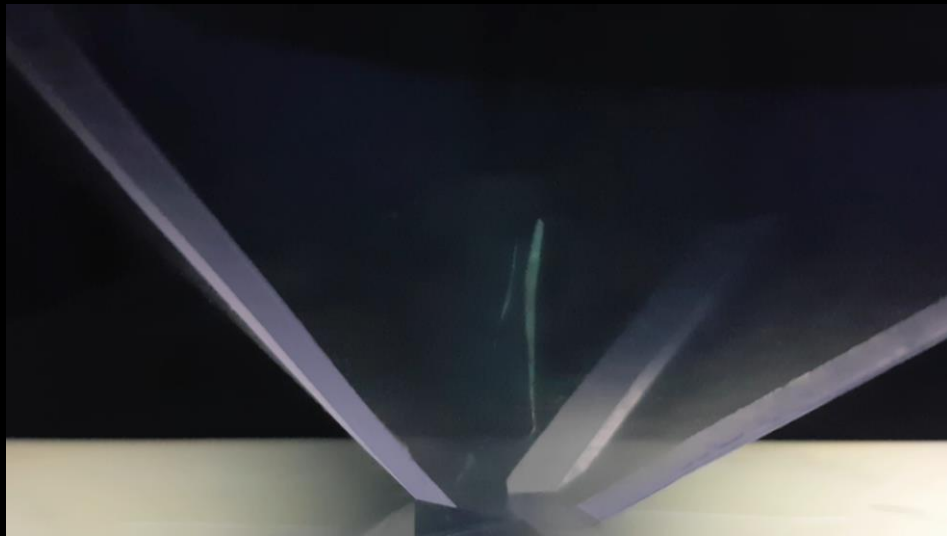
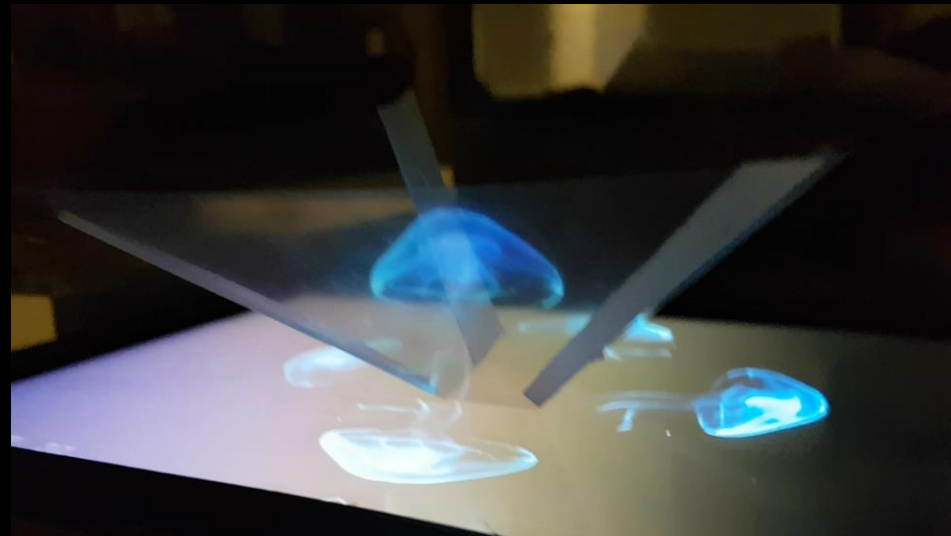
⇒ Réalité virtuelle, Réalité augmentée



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Hologramme



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

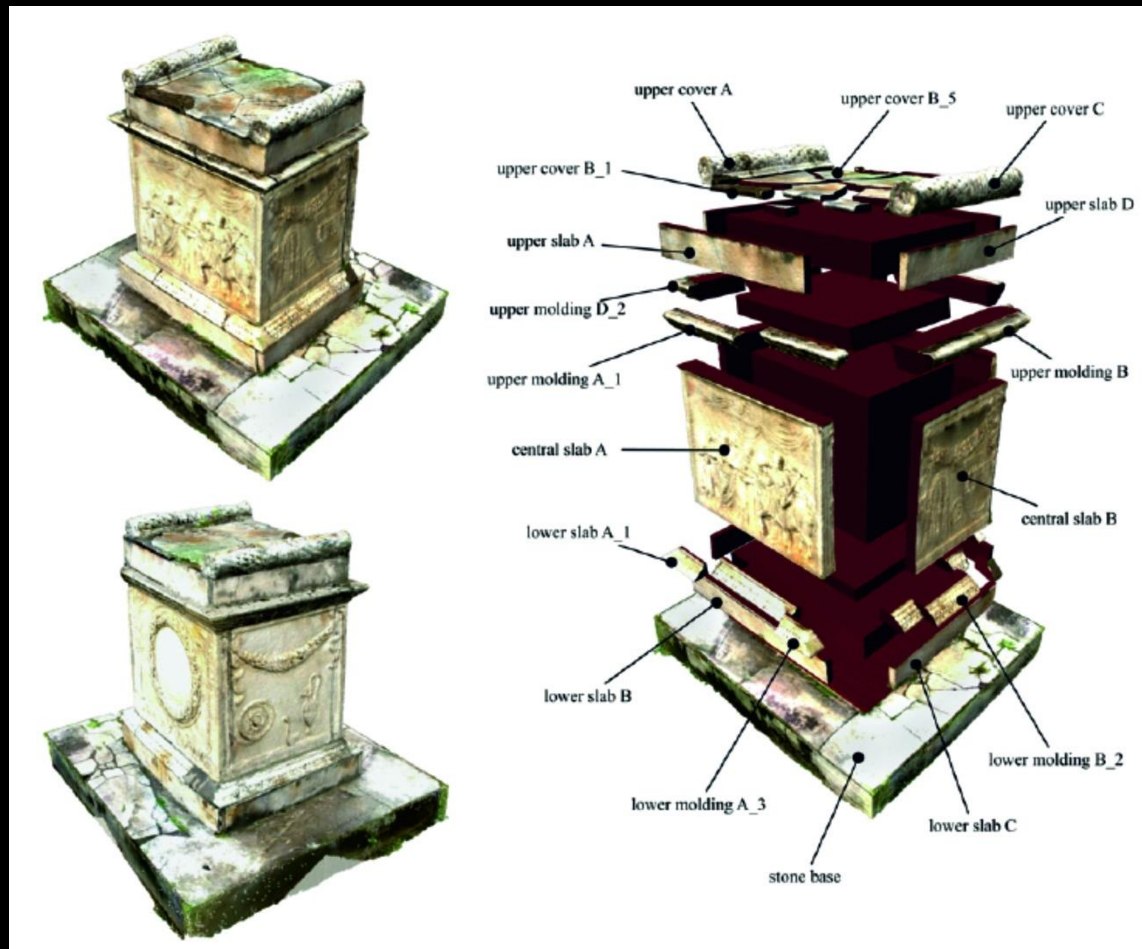
⇒ Reconstruction de la danse



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

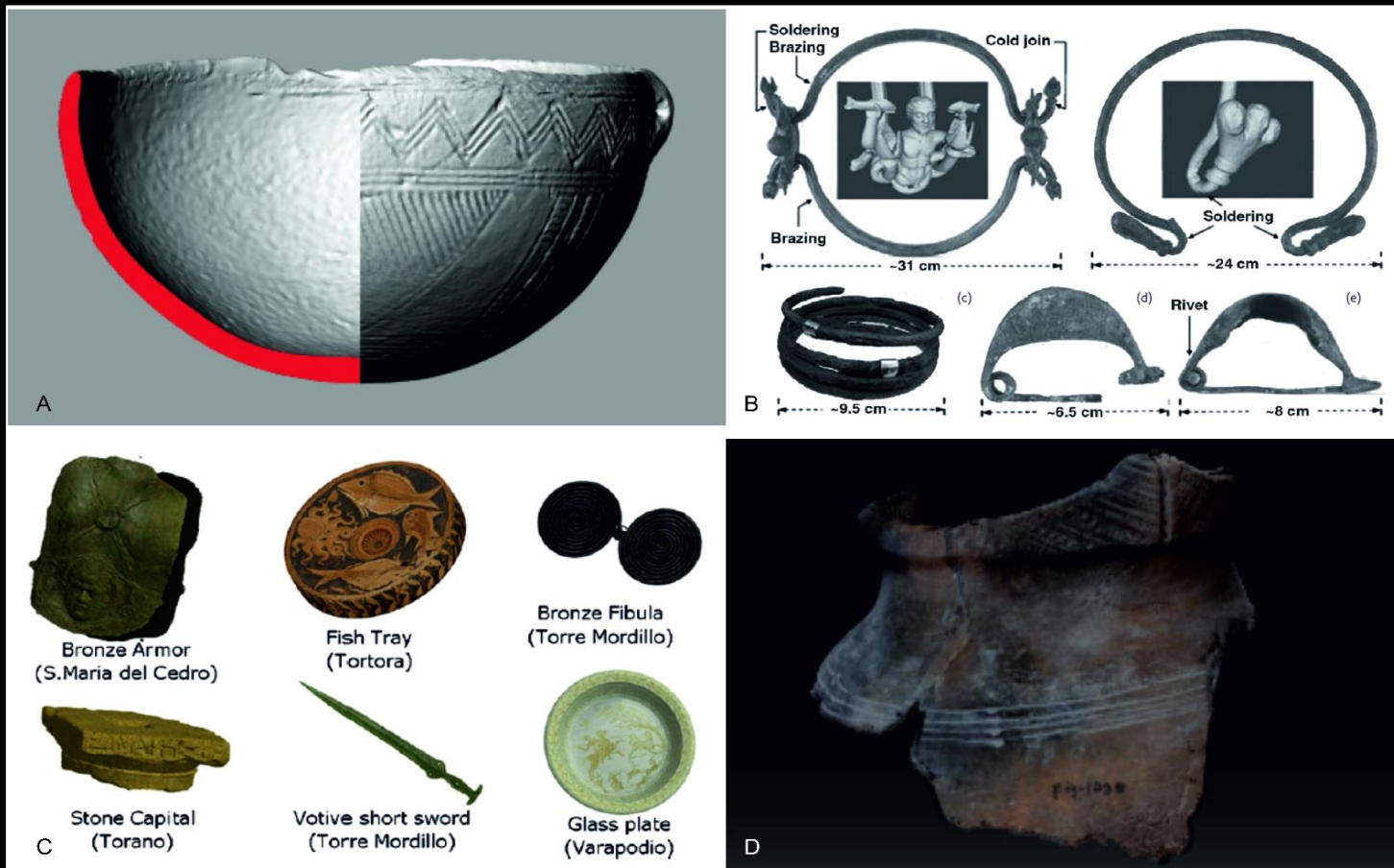
⇒ Annotations (musées, éducation, recherche)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

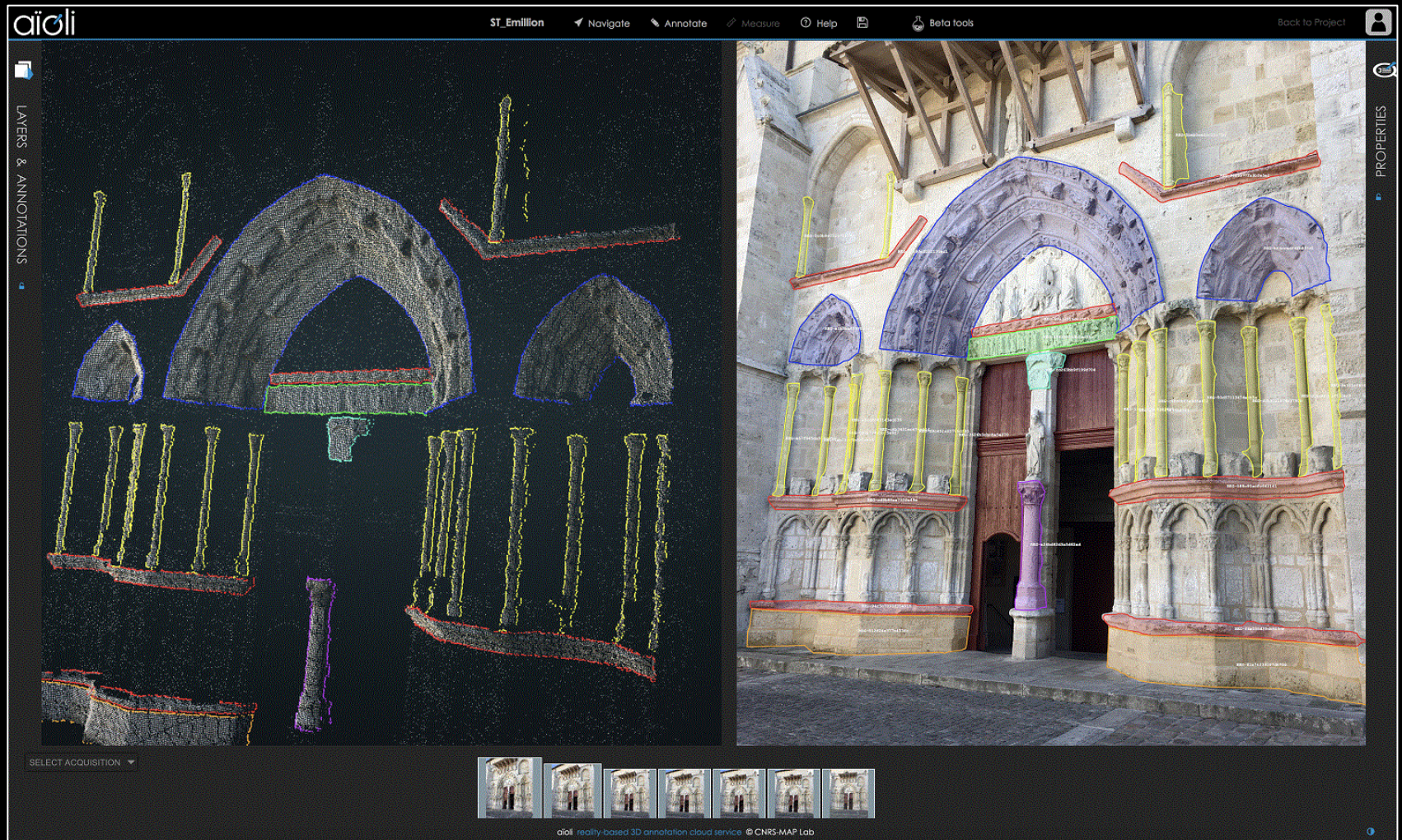
⇒ Annotations (musées, éducation, recherche)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

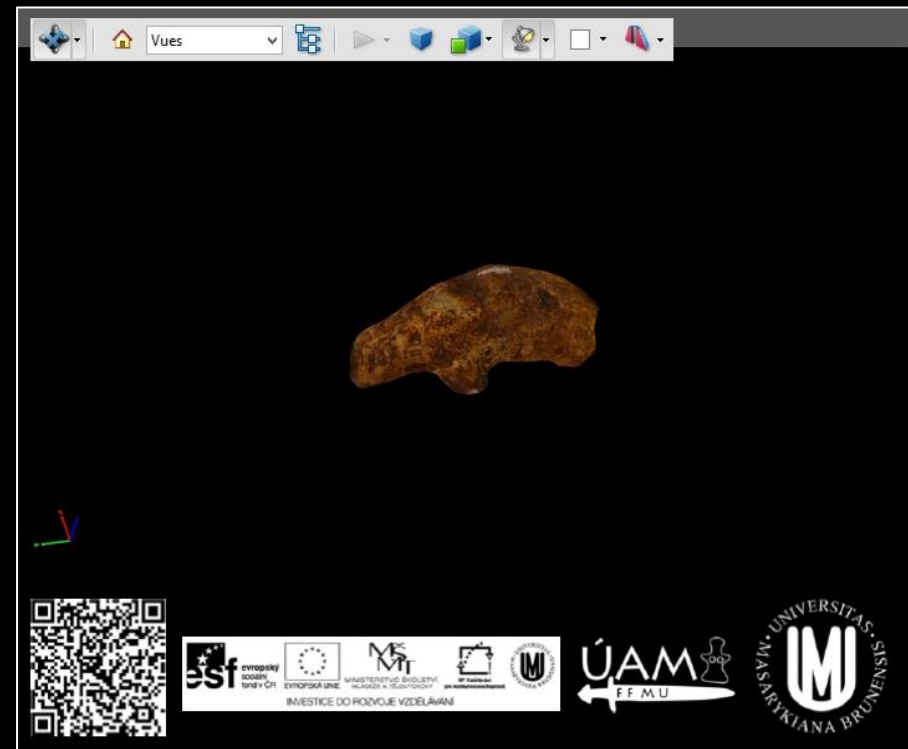
⇒ Annotations (musées, éducation, recherche)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

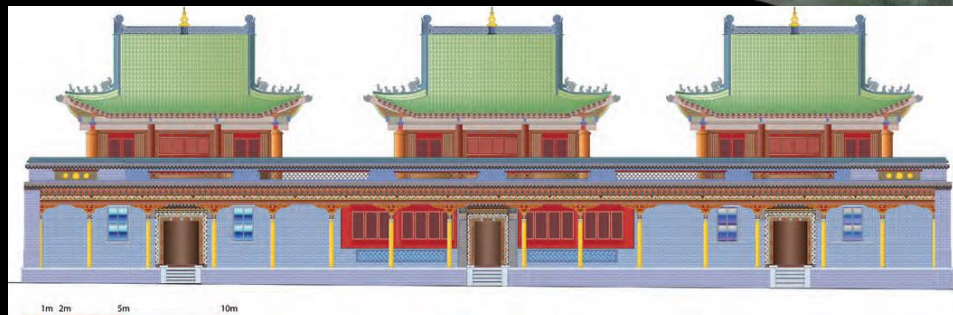
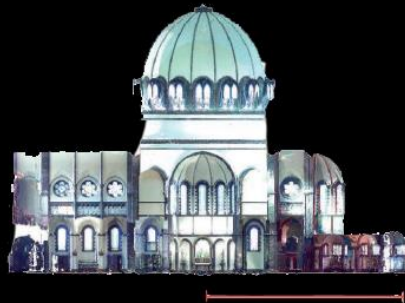
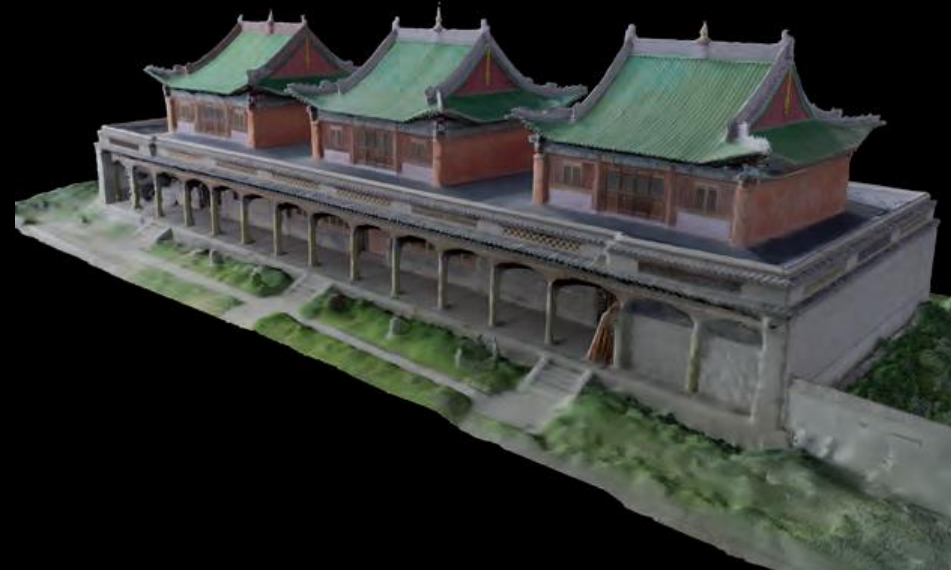
⇒ Annotations (musées, éducation, recherche)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Dessiner



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

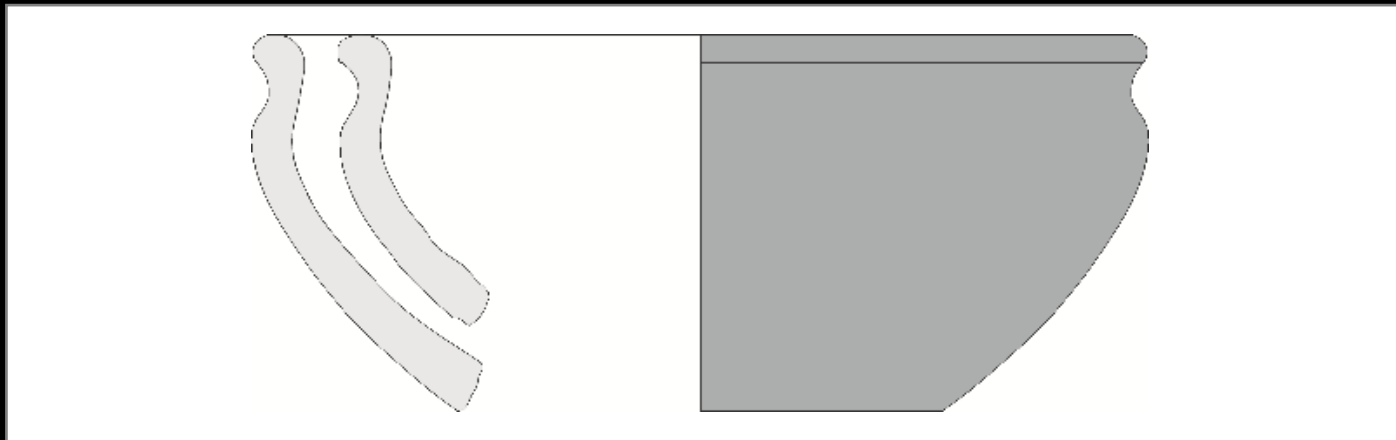
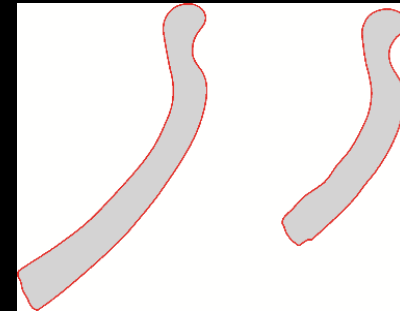
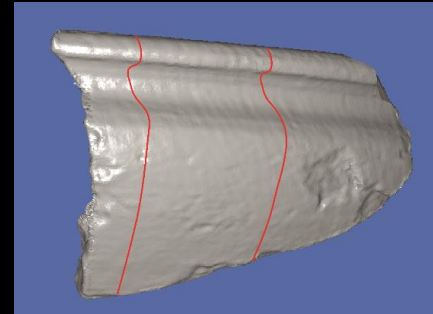
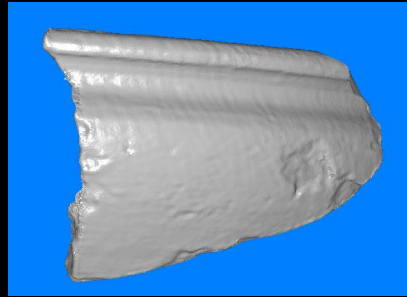
⇒ Dessiner



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

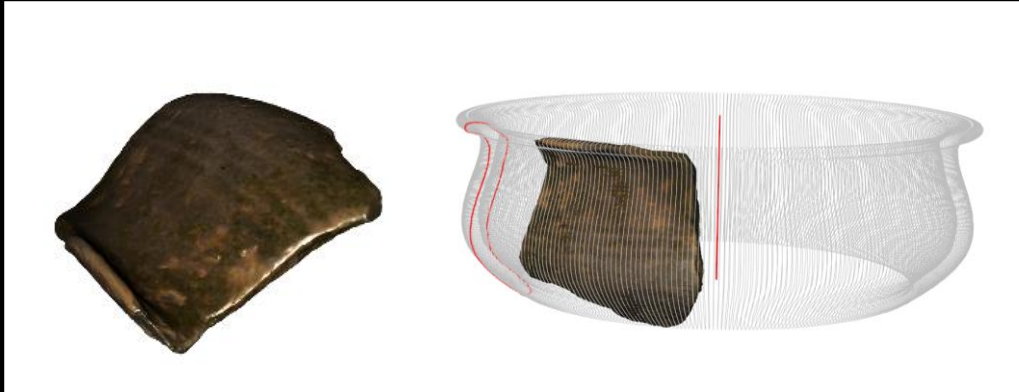
⇒ Dessiner



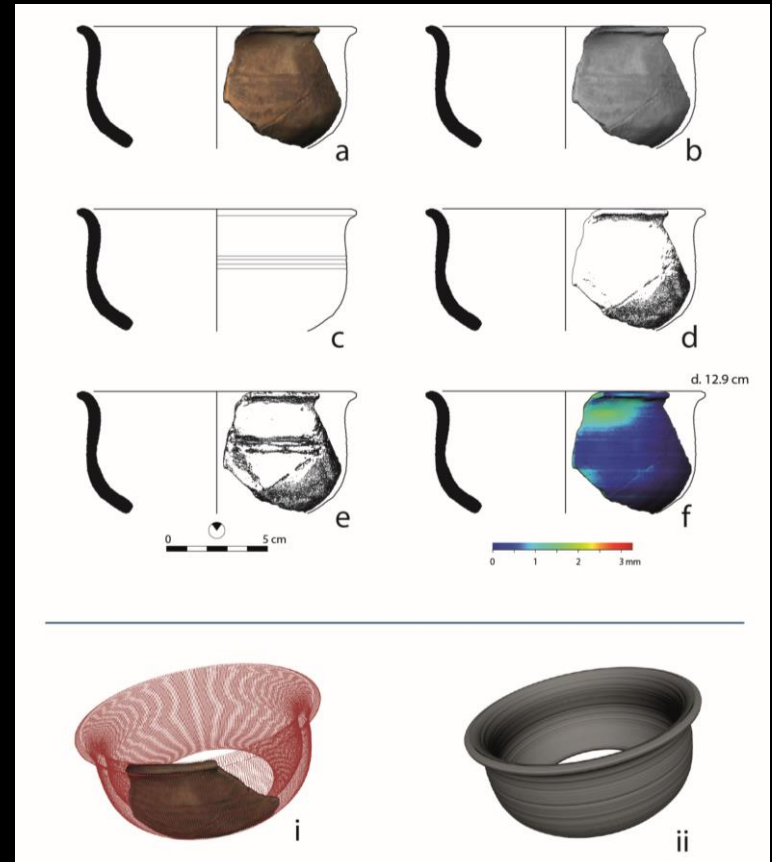
Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Dessiner (automatiquement)



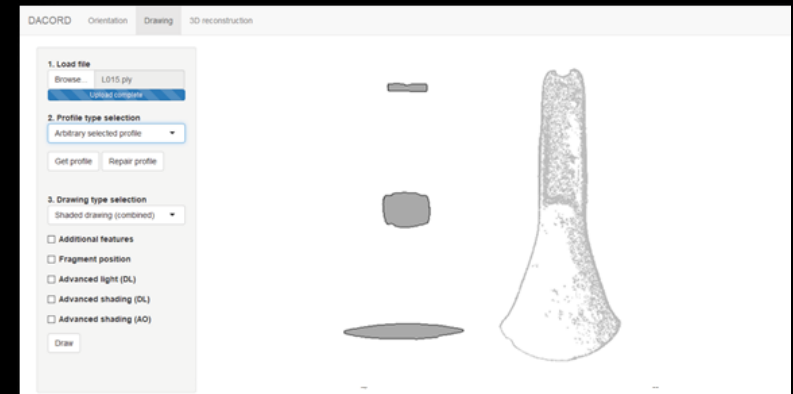
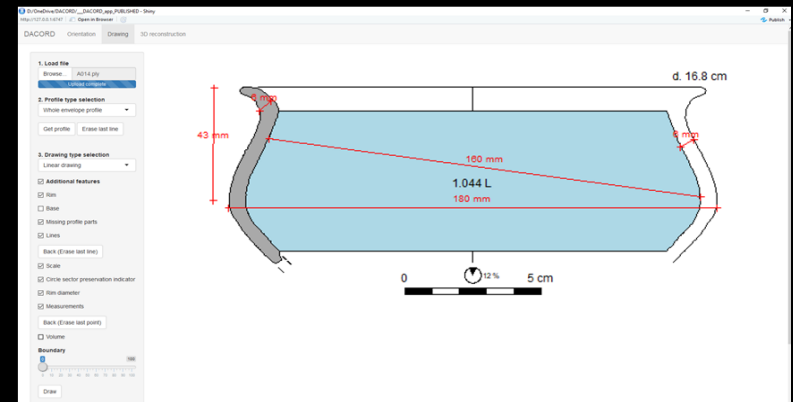
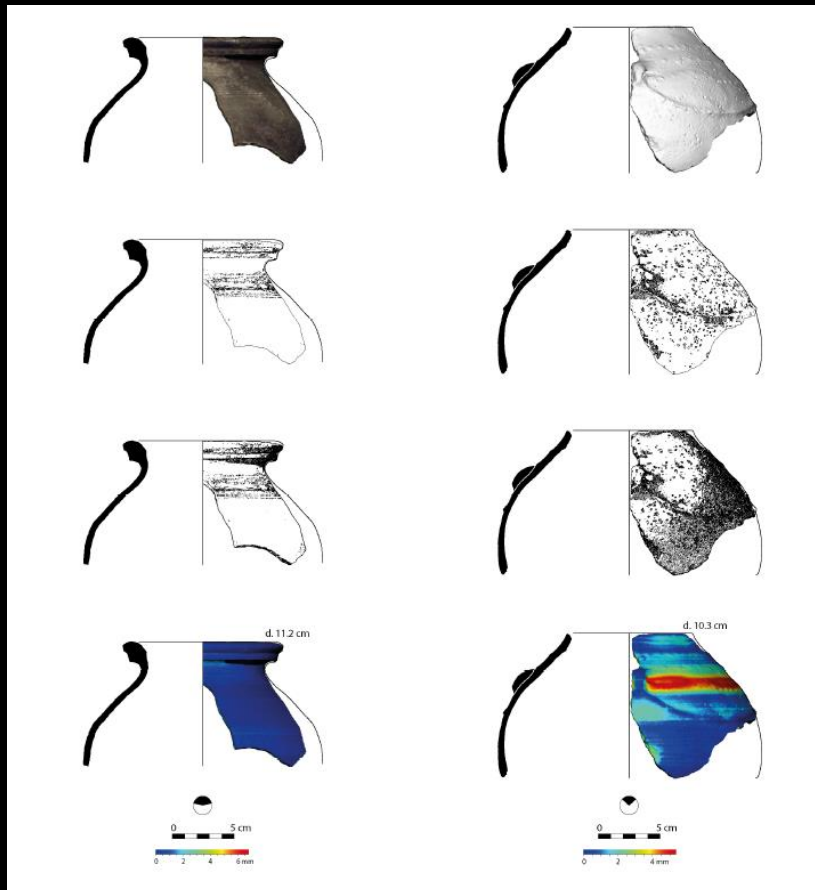
DACORD (Dessin Assisté de la Céramique par Ordinateur)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

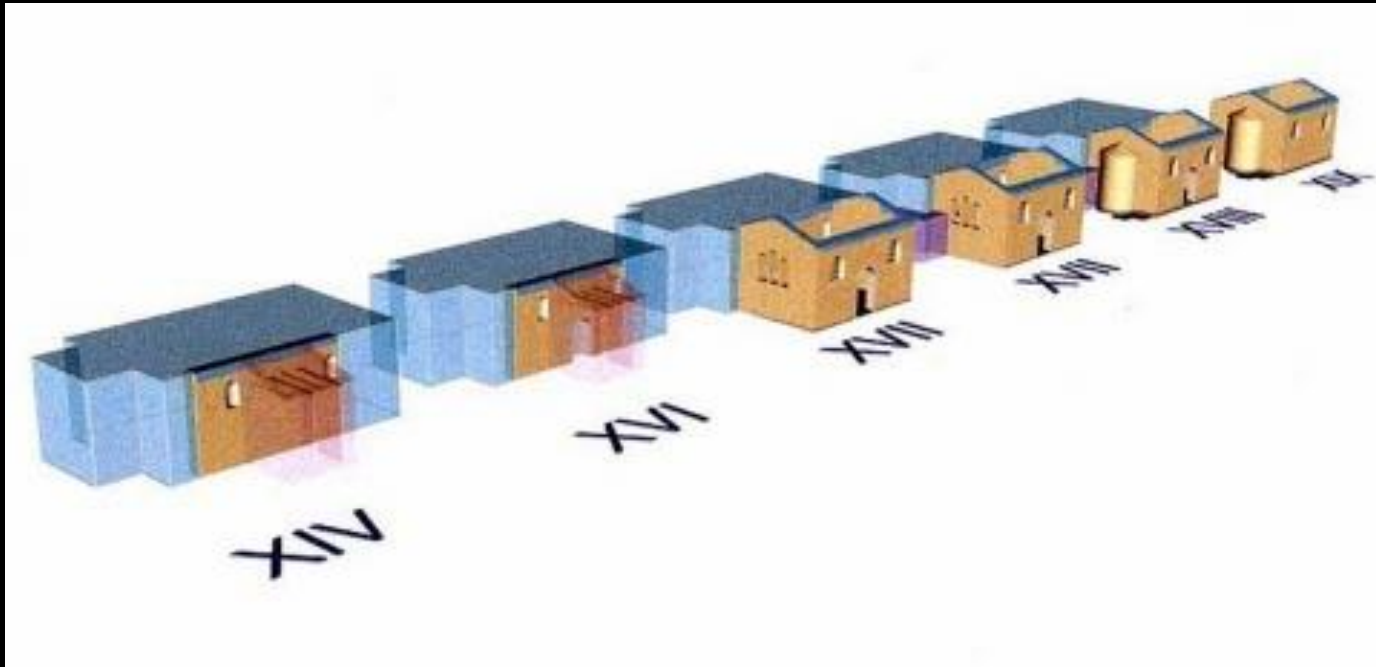
⇒ Dessiner (automatiquement)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

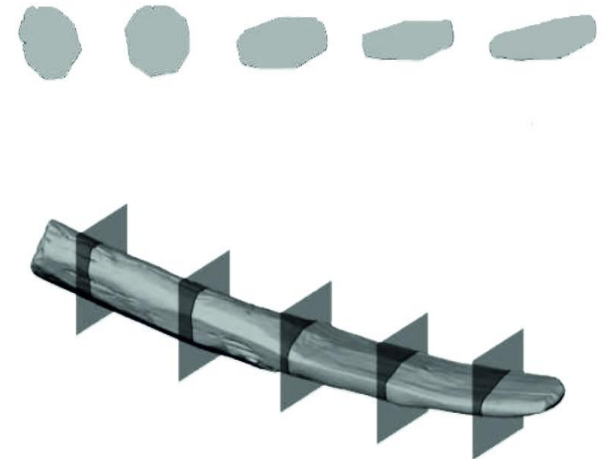
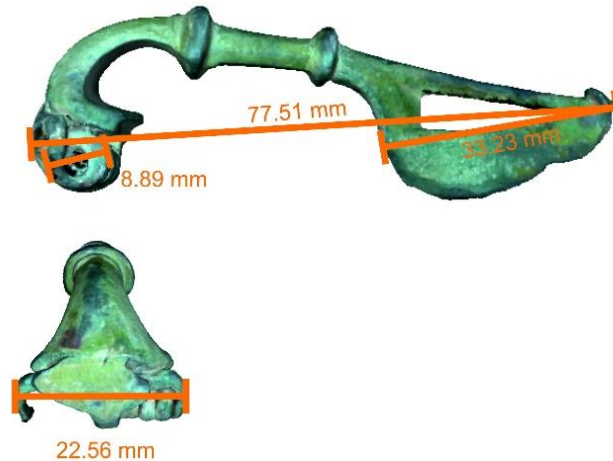
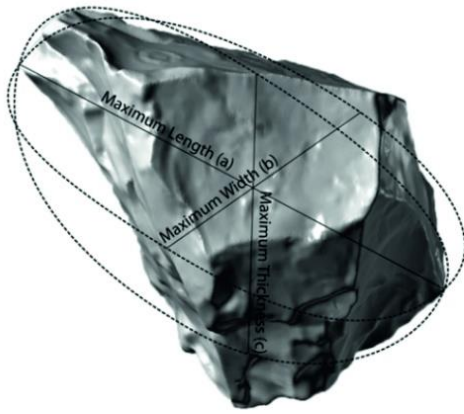
⇒ Analyser (phases des constructions/altérations des artefacts)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Analyser (distances, surfaces, volumes, textures, profiles, etc.)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

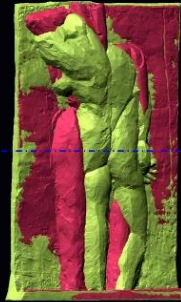
⇒ Analyser (distances, surfaces, volumes, textures, profiles, etc.)



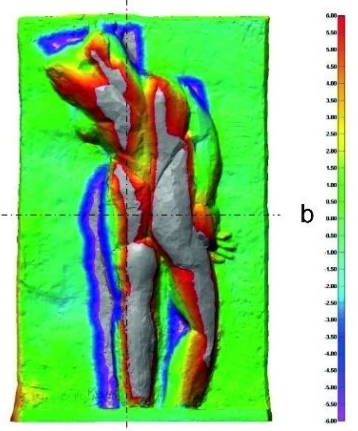
Back II (1913)



Back III (1917)



Back I a Back II



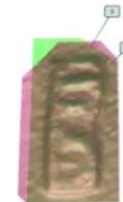
Auguste Rodin



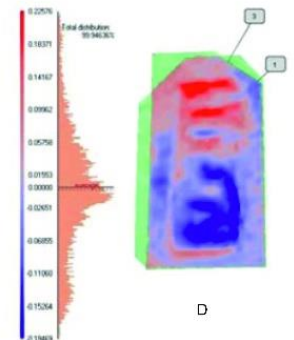
A



B



C



D

Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Analyser (Morphométrie géométrique = Analyse quantitative des formes)

Analyses des points homologues (Landmark analyses)



Analyses des contours (Outline analyses)

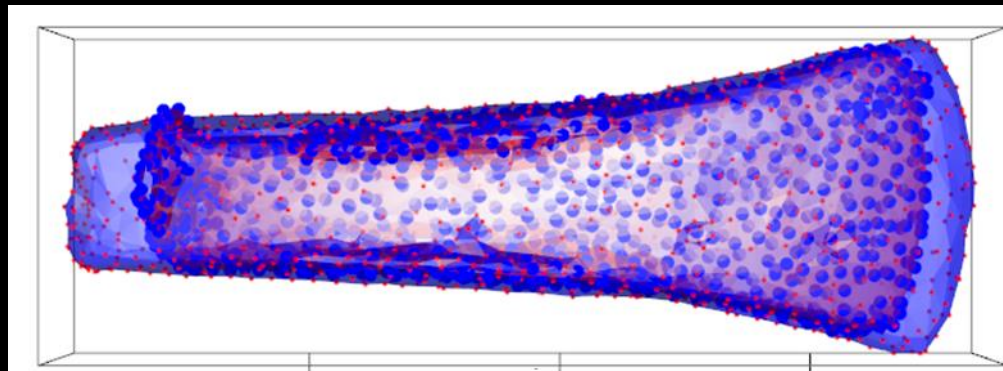
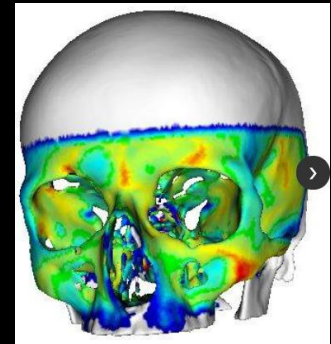
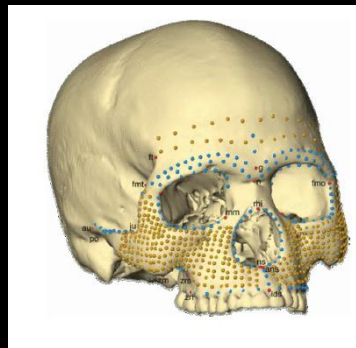
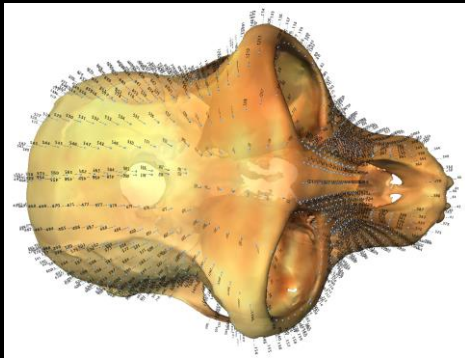


Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Analyser (Morphométrie géométrique = Analyse quantitative des formes)

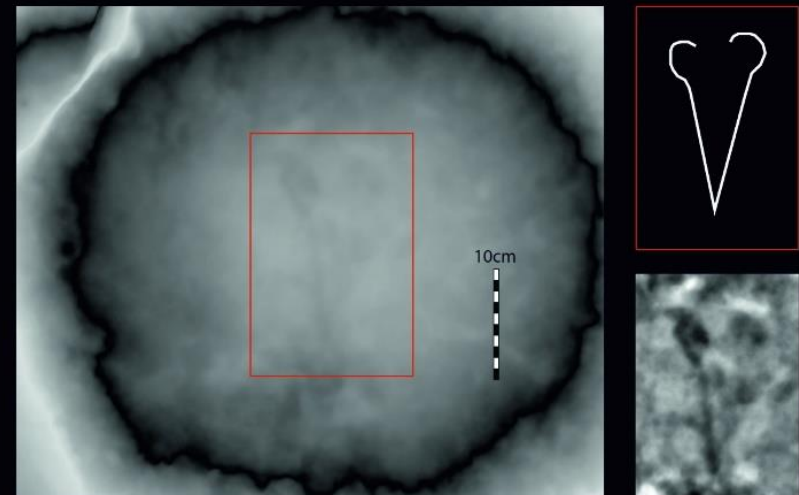
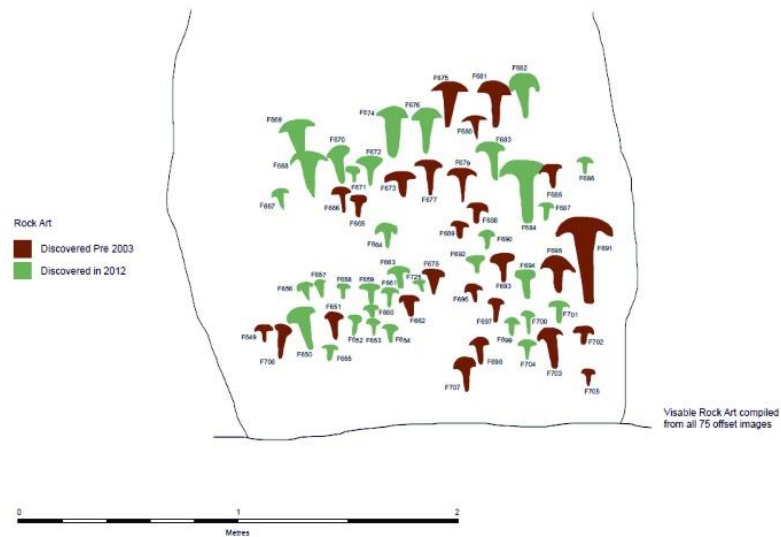
Analyses des surfaces (Surface analyses)



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

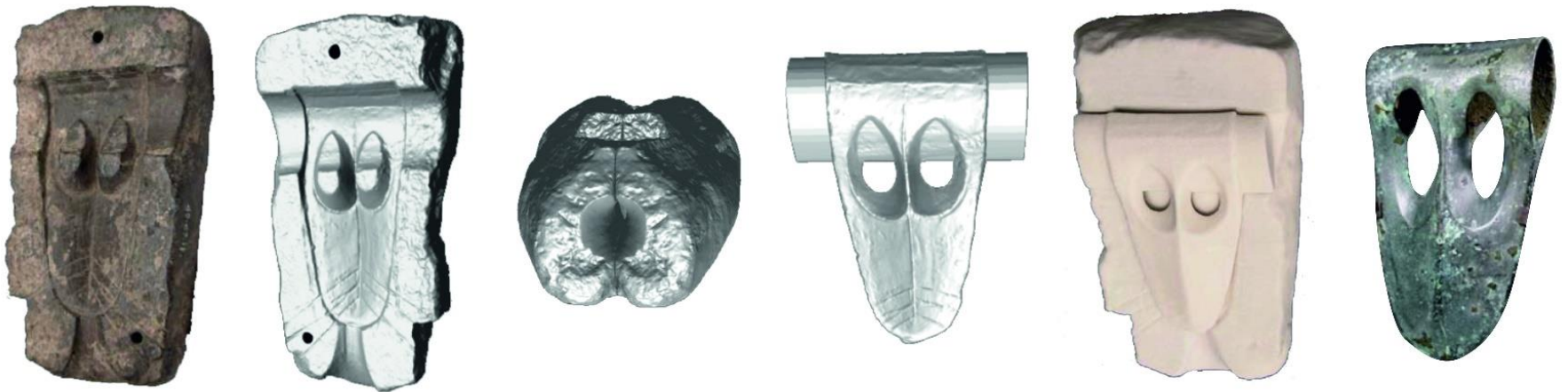
⇒ Rendre les éléments visibles



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ « Fabrication des artefacts »



Documentation en 3D

A quoi ça sert en archéologie et sur le terrain ?

⇒ Impression 3D



Références

Wilczek, J., 2013. Metody 3D akvizice a jejich aplikace v archeologii. UAM FF MU Brno. (see images and references within this document for further references of images used in this presentation).

Littérature / Images

Forel, B., Gabillot, M., Monna, F., Forel, S., Dommergues, C.H., Gerber, S., Petit, C., Mordant, C., Chateau, C., 2009. Morphometry of Middle Bronze Age palstaves by Discrete Cosine Transform. *J. Archaeol. Sci.* 36, 721–729.

Králík, M., Urbanová, P., Hyršovská, J., 2008. Hodnocení stop na stavební keramice ze středověké cihelny v Sezimově Ústí, in: Krajíc, R. (Ed.), *Středověké Cihlářství. Sezimovo Ústí Archeologie Středověkého Poddanského Města*. Jihočeská univerzita v Českých Budějovicích & Husitské muzeum v Táboře, České Budějovice & Tábor, pp. 207–276.

Monna, F., Esin, Y., Magail, J., Granjon, L., Navarro, N., Wilczek, J., Saligny, L., Couette, S., Chateau, C., 2018. Documenting carved stones by 3D modelling and

Murtiyoso, A. 2020. Relevé 3D et classification de nuages de points du patrimoine bâti. *Patrimoine* 164, 33-42.

Reveyron, N. 2002. L'apport de l'archéologie du bâti dans la monographie d'architecture. In *Situ 2. computational geography techniques – Case study of Mongolian deer stones*. *Journal of Cultural Heritage* 34, 116-128.

Urbanová, P., 2009. A Study of Human Craniofacial Variation by Using Geometric Morphometrics. Masaryk university, Brno.

van der Niet et al. 2011

Vojtas, M., Zubalík, J., Těšhnohlídek, J., Petřík, J., 2015. Archeologický průzkum terénních reliktních karpatského bojiště na východním Slovensku.

Teoreticko-metodologický úvod. In: Láník, J., Kykal, T. (eds.), *Léta do pole okovaná 1914. Proměny společnosti a státu ve válce*. Ministerstvo obrany České republiky – VHÚ Praha, Praha, 429-443.

Wilczek, J., Monna, F., Jébrane, A., Labruère-Chazal, C., Navarro, N., Couette, S., Chateau Smith, C., 2018. Computer-assisted orientation and drawing of archaeological pottery. *Journal on Computing and Cultural Heritage* 11(4): Article 22, 1-15.

Présentations / Matériaux éducatifs / Images

Nosek, V. 2013. AEB_141 Prostorová dokumentace artefaktů a vytváření 3D modelů. UAM FF MU Brno.

Travaux pratiques des étudiants de UAM FF MU Brno (V. Nosek, D. Vachůtová).

All materials and images were used here
for educational purposes only.

Références

Web / Images

https://www.google.com/search?q=micro+computed+tomography&hl=fr&biw=958&bih=952&tbm=isch&source=iu&ictx=1&fir=MmpiTlyEckSv5M%252C_br3vgHoEvQRmM%252C_%25
https://www.researchgate.net/publication/322096576_3D_Digital_Recording_of_Archaeological_Architectural_and_Artistic_Heritage/figures?lo=1
<https://memolaproject.eu/node/1620>
https://www.researchgate.net/publication/322096576_3D_Digital_Recording_of_Archaeological_Architectural_and_Artistic_Heritage/figures?lo=1&utm_source=google&utm_medium=organic
https://www.researchgate.net/publication/322096576_3D_Digital_Recording_of_Archaeological_Architectural_and_Artistic_Heritage/figures?lo=1
<https://www.nottingham.ac.uk/research/groups/cvl/software/rootrak.aspx>
http://jmfriedt.free.fr/lm_sfm_eng.pdf
<https://link.springer.com/content/pdf/10.1186/s40494-015-0033-6.pdf>
<https://www.cambridge.org/core/journals/antiquity/article/keltenblock-project-discovery-and-excavation-of-a-rich-hallstatt-grave-at-the-heuneburg-germany/06DA174F38A2CD1D2EB737222AAFCCEBA>
<https://link.springer.com/article/10.1186/s40494-015-0033-6>
<https://www.pinterest.fr/pin/317996423685657291/>
<https://mobile.twitter.com/AntiquityJ/status/1047433796247801856/photo/3>
<https://archaeologymuseum.ca/potters-in-the-past-micro-computed-tomography-of-archaeological-ceramics/>
<https://archaeology.crossrail.co.uk/exhibits/roman-cremation-urn/>
https://upload.wikimedia.org/wikipedia/commons/e/e3/Scanner_3D_Konica_Minolta_VI-9i.jpg
https://curis.ku.dk/ws/files/37457171/Harvig_archaeometry_2012.pdf
<https://www.sciencedirect.com/science/article/abs/pii/S2352409X1630013X>
<https://appleinsider.com/articles/20/10/13/iphone-12-pro-lidar-sensor-allows-for-6x-faster-low-light-autofocus-instant-ar>
<https://www.solidxperts.com/scanner-eva-fr/>
<https://fr.geospatial.trimble.com/products-and-solutions/laser-scanning>
http://atelier3d.levillage.org/local/cache-vignettes/L1078xH757/Deroule_ortho_tire_du_scan_3D_Barbezieux-0d4e1.jpg?1579493750
<https://www.stratovan.com/sites/default/files/LandmarkCap3.jpg>
<https://sourceforge.net/projects/morpho-rpackage/>
<https://www.anarchiel.com>
<https://www.biology-online.org>

All materials and images were used here
for educational purposes only.