ANATOMOGRAPHICS

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3D IMAGING
SURVEY
ANATOMY
ARCHITECTURE

‘Anatomographics’ is a neologism that intends to embrace the wide range of digital representations and images dealing with anatomy. However, this last term seems by now no more confined to the medical disciplines but instead able to describe approaches and methodologies that are typical of other fields of expertise. In this framework, the paper tries to outline how much the digital revolution has influenced medical and architectural ‘anatomographics’ providing an insight on common approaches, data processing and visualization.
The analysis carried out on some representative examples clearly show that 3D modelling and 3D imaging are standing out as major interleaved methodologies in which geometric points on one side and pixels on the other create new unexpected interactive tools to understand the anatomic complexity of bodies and buildings.

INTRODUCTION

Νοεῖν οὐκ ἔστιν ἄνευ φαντάσματος. It is impossible to think without an image.

This very well-known quote from Aristotle (4th century B.C.E./1972, 450a 1; 4th century B.C.E./1961, 431a 15-20 & 432a 8-12) still synthesises at best the role that images play in that complicated recursive process of abstraction, creation and construction that we call 'thinking'. This high-end human ability (maybe the most valuable evolutionary advantage of our species) actually exploits images both in the inception phase of the workflow and at its end, where they represent instead the ultimate result of thinking. Regardless their material or non-material nature, images thus represent a crucial fuel for our mental speculation of which 'knowledge' is certainly an essential part. By means of images, in fact, we get in touch with the environment around us, we create abstract configurations of it, we imagine new layouts and we design tools and processes to manipulate it.

The variable nature of images in connection with the imaginative/perceptive process has been a traditional subject of investigation for researchers in the Representation area (Belardi, Cirafici, Di Luggo, Dotto, Gay, Maggio & Quici, 2015; De Rubertis & Clemente, 2001) even though in the last years it has become collateral in comparison with other topics (e.g. 3D capturing, 3D modelling, etc.).

Recently, though, some new and original studies (Casale, 2018; Cervellini, 2012; Cohen-Or & Kaufman, 1995; Luigini & Panciroli, 2018) have been revitalizing the debate on images, suggesting both a more comprehensive general theory and relationships that visibly exceed the limits of our traditional Representation boundaries. From this standpoint, Medicine and Architecture have been living parallel lives: though very different, they both base a relevant part of their core activities on images production, reading, interaction (Di Giamberardino, Iacoviello, Tavares, & Jorge, 2012). In my opinion, the utmost field of this emerging consonance is 'anatomy', term that by now seems no more confined to the medical disciplines but instead able to describe approaches and methodologies that equally belong to other fields of expertise like Architecture. In this framework, 'anatomographics' is the neologism with which I intend to embrace the wide range of digital representations and images dealing with anatomy in this broader sense. This paper tries to outline how much the digital revolution has influenced medical and architectural 'anatomographics' providing an insight on common approaches, data processing and visualisation.

ANATOMOGRAPHICS AND MODELS

Anatomographics are definitely 'images,' namely bidimensional rendered figures. However, they always act also as 'representations'. The difference is quite easy to understand: the former is a product valuable in itself (like a work of art), the latter instead is the last ring of a precise chain of events (geometrical, physical, psychical) that binds the bidimensional image to the original 3D object in a complex correspondence that under certain circumstances could become biunivocal (Bianchini, 2014). The Representation Methods (perspective, orthogonal projections, axonometry and contour projections) considered in the wider and rigorous framework of the Projective Geometry, are the tools that allow for the establishment, control and validation of the above mentioned biunivocal consistency. The whole workflow governing this process assumes as a pre-requirement the correspondence between the real object and its geometric abstraction, the so-called Geometric Model (Migliari, 2004).

Through the application of the traditional Representation Methods (Docci & Migliari, 1992), this abstract counterpart of reality becomes eventually a Bidimensional Graphic Model that generally takes the form of a line drawing or a rendered figure. All these 2D products, collected in books or atlas, still represent the key tool for students in order to learn

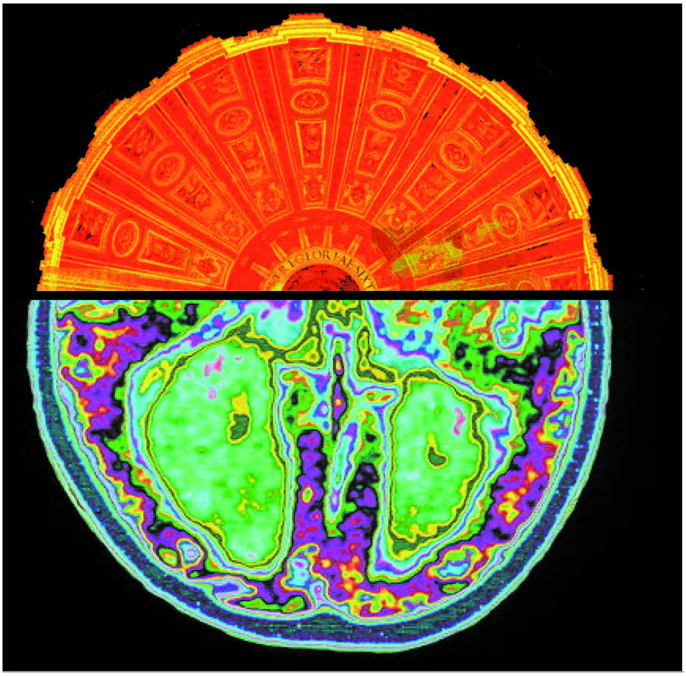


Fig. 1 Anatomographics: St Peter's Dome point cloud (above) and functional RNM (below).

and understand the spatial configurations and relationships of the 3D structures that they will deal with during their studies and career. In brief, 2D models allow for a 3D 'mental' reconstruction of structures' 3D features. Even if 3D 'material' models traditionally do provide an important contribution for this same knowledge process, their overall impact has always been less relevant essentially for practical reasons (Bianchini, 2007).

Digital modelling systems have actually introduced some relevant novelty in this standard workflow. In fact, while for the Bidimensional Graphic Models the process establishes a biunivocal correspondence between the object and its graphic representation by means of projection and section operations, for 3D Digital Models this correspondence is established between spaces: the real world and the virtual one created by 3D modelling software. They are thus very different from traditional 3D Models that live in our same world as real objects being subjected to same limitations of any manufacturing process. Besides, they are always scaled with respect to the original with an evident loss of accuracy in metric terms.

3D modelling software, instead, more than producing a mere representation of the object provides the possibility to interact with an entire digital environment that, initially empty, is step by step populated by elements that together build a virtual replica of the object.

This process establishes a direct correspondence 1:1 between the physical and the virtual space: to each small objectual area Pr identified by its coordinates *xr*, *yr*, *zr* in the real space corresponds in fact a geometric virtual point Pv univocally identified by the Cartesian triplet *xv*, *yv*, *zv* (Bianchini, 2007, 2014). Hence, the digital environment created by 3D modelling software provides an actual spatial scaffolding for all the following constructions and, from this standpoint, the computer screen becomes the interface between two parallel universes: the real one on this side of the monitor, the virtual instead on the other. However, it represents also the ultimate limit of our exploration, the Maya Veil that we can never cross and that causes our interaction with all virtual entities (navigation, modelling and manipulation) to occur only using special, digital tools. Something similar to the robotic arms that allow the no-contact handling of hazardous objects of substances.

Virtual models are thus certainly three-dimensional, but on the other hand are also non-material. Made of numeric data, they do not produce in fact any material element capable even of a simple ‘evocation’ of the original object. The anatomographical image we interact with on the monitor is actually a ‘secondary’ projection/section product derived from this 3D non-material model and often built directly by the visualisation hardware of the workstation. Furthermore, while using graphic models we have to decide beforehand the type of representation without the possibility of changing it on the fly (if we are drafting a perspective we cannot change it in an axonometry at will). Non-material ones, instead, leave users free to change their mind in any moment shifting from one to another even accessing simultaneous different view just acting on the visualisation options.

This is in my opinion one of the main reasons why 3D modelling and the connected digital representations forms have by now become commonplace in the design, knowledge and communication of the spatial features of real structures. In the sense, I have proposed in the previous lines for the word 'anatomy', both architecture and medicine are profiting of modelling software potentials especially in terms of exploration, manipulation and modification of the space.

PIXELS, VOXELS, POINTS

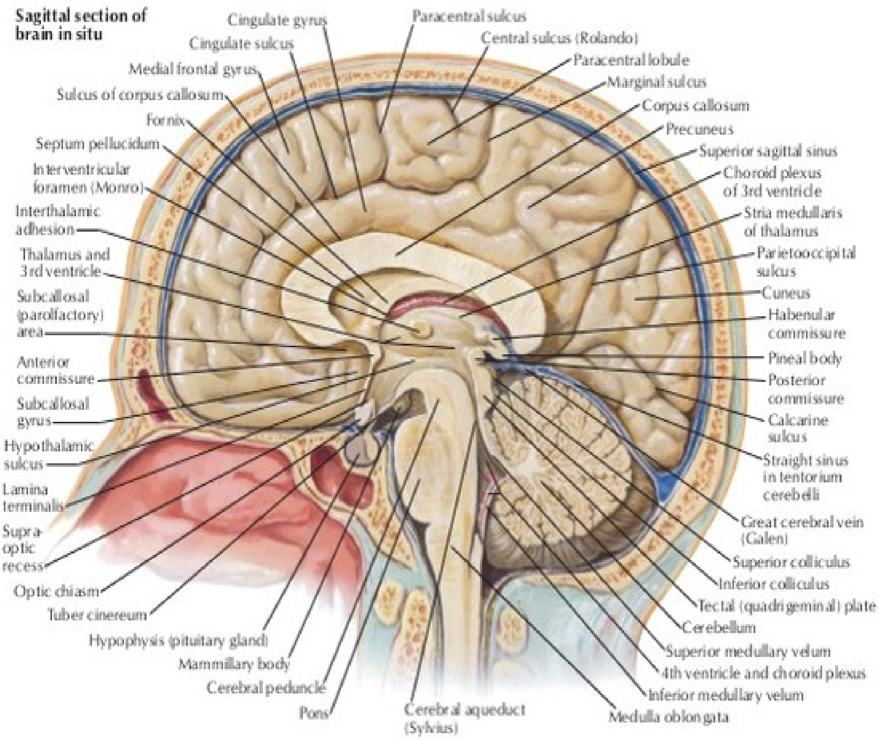
All representations we consider in this paper (2D, 3D, conventional, digital, etc.) do share a common character that allow for their general grouping under the category Model. This common denominator corresponds theoretically and operationally to the procedure used to transform objectual areas in geometric points, pixels or voxels. Although this transformation relays on the common projective background discussed so far, however it presents great differences between architectural and medical applications. This diversity, apparently intrinsic to architecture and medicine, depends instead on the material composition of the structures investigated and on the specific aim of this investigation. In fact, while architecture shows a prevalent interest in the 'outer skin' of constructions, medicine's quest has always been tending in 'going beyond the skin' in order to reveal, understand and eventually intervene on biological structures. In my opinion, this one of the key factors determining the almost incompatible approach we historically observe in the architectural and medical modelling: the former essentially oriented towards quantity and geometry, the latter instead to quality, composition and functionality of structures.

Despite this divergence, still both disciplines have continued to share graphic representations and drawing as key

Fig. 2 Frank N. Netter, Atlas of Human Anatomy (Netter 1989, p. 2).

NEUROANATOMY

Cerebrum: Medial Views



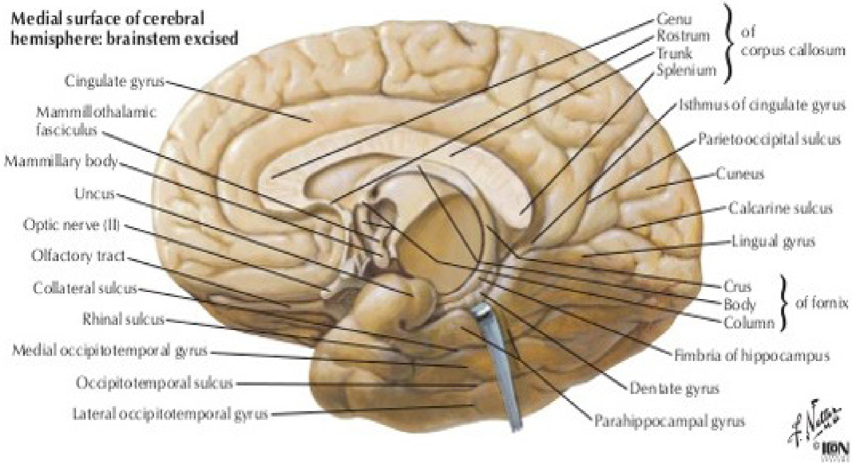
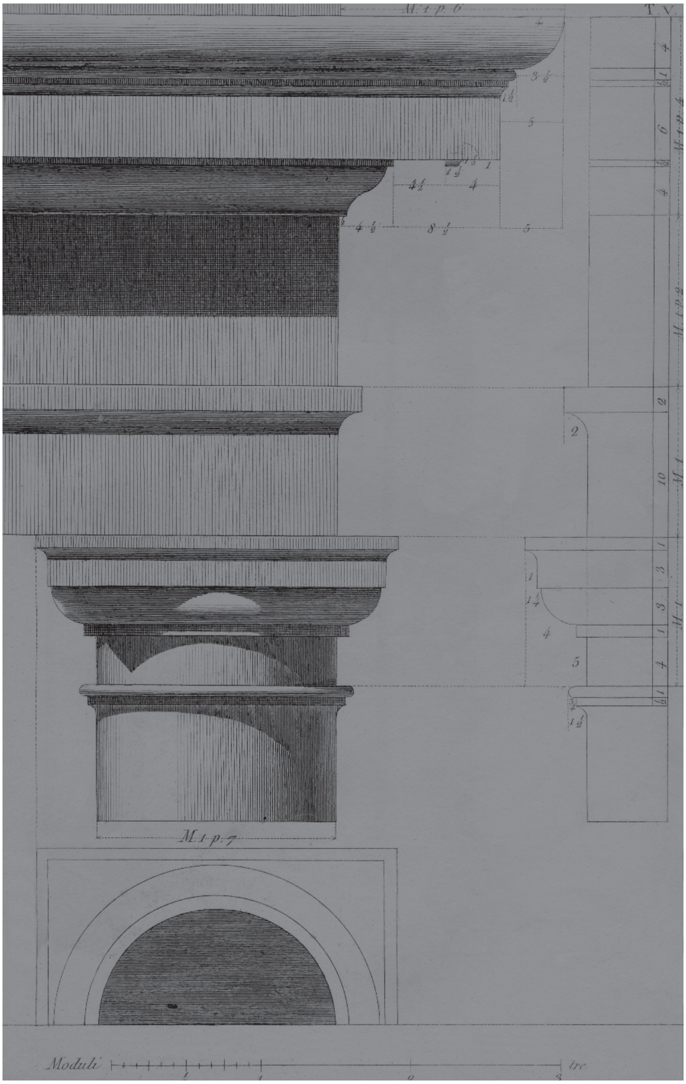


Fig. 3 Jacopo Barozzi da Vignola, *Tuscan order* (Barozzi da Vignola, 1889, plate III).



‘technologies’ to acquire, establish and transmit information. In other words, to create the reference database about families of structures as well as specific ones. Architectural manuals and anatomic atlas, flourished since the XV century, provide clear evidence of this phenomenon and even today still represent an untouched vehicle of knowledge transfer (Figures 2, 3). Nevertheless, technology has been increasingly providing new instruments tending to enhance and finally transform this consolidated scenario. The core of this change is strictly connected to the use of a new class of images no more produced by a skilled painter or sketcher, but instead automatically generated by some kind of equipment: photography and radiography. Both share the same projective principles: a family of straight lines (light from the object, the x-rays from the radioactive source), converging in a center of projection (the focal point of the camera or of the radiographic equipment) and cut by a plane (the film). For the first time in history, there was a way on one side to document point by point the surface of objects and, on the other, to materialise on a surface the image of biological structures that where beyond the skin of living bodies (Figures 4, 5).

Since these fundamental steps, terrific progresses have been made even before the so-called digital revolution. Photography has quickly developed into photogrammetry thanks to the theoretical achievements of Guido Hauck (Migliari, 1989) at the end of XIX century becoming a key technology for surveying built artefacts. Thanks to continuous technological achievements, it has maintained its role of high-end technology until the end of XX century (Bianchini, 2004). Radiography followed a different path (Figure 6): before becoming commonplace, it had not only to solve the technological issues connected with dimensions, radioactive materials supply and general safety, but also with the 'reading' of the images impressed on the film. Differently from light rays that allow the precise reconstruction of the straight line connecting the objectual area to the corresponding point of the photograph, the emitted x-ray crosses completely the biological structures between the emitter and the film so that each point of the image could represent any point of the objectual layers encountered. This 'geometric' uncertainty actually affects the representation itself as the shading of each point directly depends on the average density of the structures crossed.

In this framework, while a photograph is 'iconic', namely a generally and immediately recognizable representation

Fig. 4 Wilhelm Röntgen, *X-ray by Wilhelm Röntgen of Albert von Kölliker's hand*, 1896. Image courtesy: Wikimedia Commons, the free media repository.

Fig. 5 Louis Daguerre, Picture of Boulevard du Temple, 1838. https://en.wikipedia.org/wiki/File:Boulevard_du_Temple_by_Daguerre.jpg.

of the pictured object, radiographs appear instead vague simulacra of the portrayed body and undetailed representations of its structures (Figures 6, 7). In fact, soon after the discovering of the physics of the phenomenon and the envisioning of its medical applications, it has taken much time to develop a method capable to backread the 3D source from the impressed image. The strategy, still valid, has been twofold: on one side set up reference standard images of organisms adopting a statistic approach, on the other enlighten in terms of pathology any possible variation with respect with this standard.

Despite the very quick and very wide success of this technology for diagnosis and some improvements in terms of accuracy, the 'modelling', i.e. the reconstruction of the biunivocal correspondence between 3D biological areas and points on the image was totally depending on the skill of the reader. This scenario has though radically changed after the migration of this method into the digital environment.

The transition from analogic films, always one and only, to digital images made of pixels has been the first crucial step. Images have in fact somehow 'dematerialized' becoming *raster* files, namely a matrix of values each one representing a punctual reading of the energy received from the x-ray

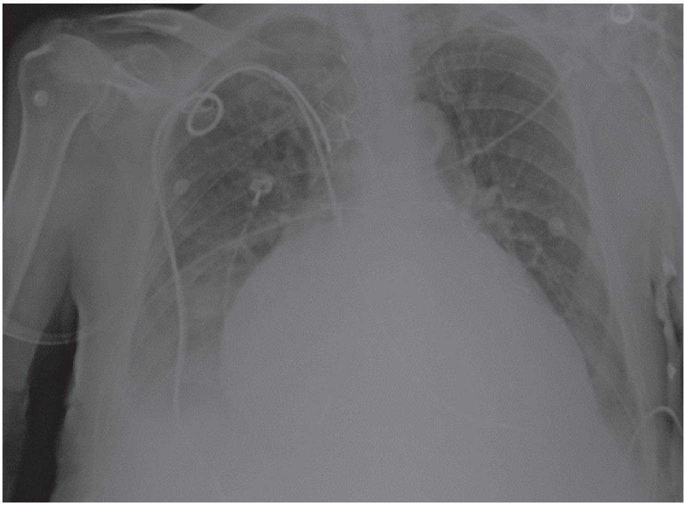


Fig. 6 Sheng Chen and Yuantao Cai, *Enhancement of Chest Radiograph in Emergency Intensive Care Unit by Means of Reverse Anisotropic Diffusion-Based Unsharp Masking Model*.

source. From this ordered set of data, the classical impressions on a film or their screen projections are just two of the possible secondary elaborations of the same original file. The above-mentioned transformation led quickly to envisage an x-ray generator that, moving around the body and projecting on detectors positioned on the opposite side of its circular trajectory, could generate several shots of the same structures from different angles. It is the well-known Computed Axial Tomography (CAT) now become Computed Tomography (CT) (Fishman et al., 1991; Toennies, 2017. Figure 8).

In this case, all radiographs have in common the internal orientation and density as well as the position in space of each center of projection as the movement of the emitter

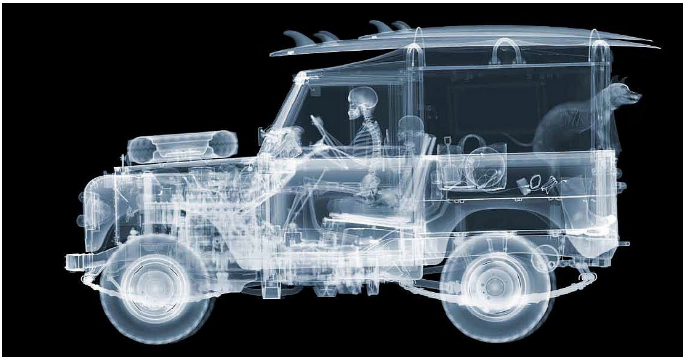


Fig. 7 Nick Veasey, *1972 Land Rover Surfer*, 2018. ÆRENA Galleries and Gardens, Ed. 12/25 (2018).

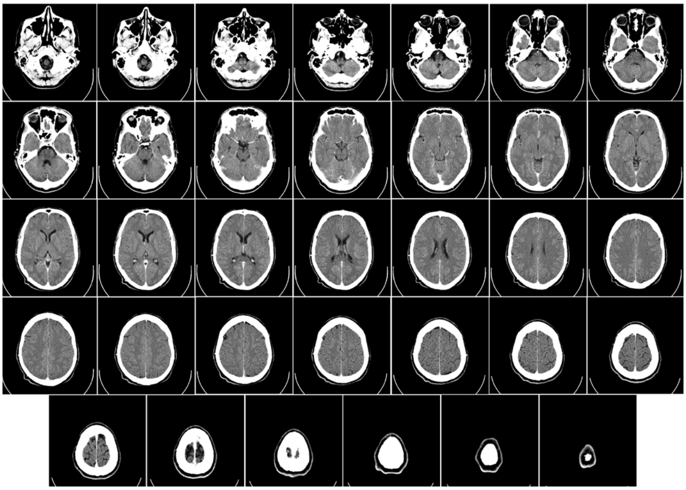


Fig. 8 TC Images. https://upload.wikimedia.org/wikipedia/commons/5/50/Computed_tomography_of_human_brain_-_large.png.

with respect to the object is tracked. It is quite easy to recognize the same geometric background of photogrammetry, both in its analogic 'vintage' version and in the present one (the so-called Structure from Motion - SfM). The projective core of both systems lays on the 3D reconstruction of several projective rays all crossing in a certain 3D point. While SfM can directly achieve this result just acknowledging the geometry of the system, CT must instead introduce an additional computation. As we already mentioned, an x-ray produces on the projection plane (receiver) a point (pixel) that is not the 2D projection of a corresponding 3D source but instead of an entire segment, namely the intersection with the crossed structure. The visual representation of this raw data (the sinogram) is not sufficient for interpretation. In fact, it must be processed using the so-called 'tomographic reconstruction' that produces a series of cross-sectional images where pixels are displayed in terms of relative radiodensity according to the Hounsfield scale (Toennies, 2017). These 2D images not only are the result of a sophisticated mathematical computing but also the product of a secondary projection that grants them a clear iconic value. CT images take in fact the form of slices cut perpendicular to the feet-head direction of the patient. They thus approximate the sections we could perform on the real body and from this feature descends the iconic value we mentioned before. In this framework, it connects directly with the system of representation widely used in the pages of anatomy treatises. Even if the mathematics underneath is much complicated (Bradley, 2008), we can intuitively understand that from an ordered spatial sequence of planar tomographies we can build a 3D model just adding 'thickness' to each slice. This process called 'voxelization' (Cohen-Or & Kaufman, 1995. Figure 9) actually transforms the bidimensional pixels into their solid counterpart: the 3D voxels. Thanks to this sophisticated interpolation, CT allows for the construction of 3D models of the investigated structure achieving the original objective of the whole process: create a sound and reliable correspondence between 3D portions of the real world and 3D points of the virtual one. Nowadays, we all know that CT represents only a fractional part of medical imaging. In fact, the Nuclear Magnetic Resonance (NMR), Echography, Positron Emission Tomography (PET) and others have all become powerful means for the anatomical investigations. For its level of accuracy and very low impact on living tissues, NMR has quickly become a leading method. Although its technical, operational

Fig. 9 Voxelization. Immagine da http://cdn.wolfire.com/blog/voxel/voxels.jpg.

Fig. 10 Bianchini C., S. Peter's Dome, 3D texturized point cloud from scanner.

and mathematical backgrounds are incredibly more sophisticated of all others imaging techniques (Bradley, 2008), however it shares the same principles and objectives: discretize a physical effect by numeric values, locate them in a common 3D space as voxels, and build a general 3D numeric model as collection of all voxels. None of these extraordinary technological achievements would have determined the pervasive presence of these imaging products without a digital infrastructure capable to store, process and represent/render the mentioned above 3D numeric models: 3D modelling software. As end-users, we tend to focus on the final outputs (images) and bypass the conceptual implications we have discussed at the beginning about the 'magical' effect triggered when launching any 3D modeller, namely the creation of a 3D 'parallel' virtual space.

Capturing technologies for architecture are quite different from those addressing medical issues. Nevertheless, they lead to very similar outcomes both in term of imaging and 3D modelling. The background geometry is though very different even if it is applied to the same 3D virtual environment. The 'solid' voxels become in fact three-dimensional points, that is to say elements identified in the 3D space by a triplet of coordinates. What we see

Fig. 11 Bianchini C., Amman Nymphaeum, 3D texturized point cloud from SfM.

on screen is actually the projection and rendering of such geometric points. Furthermore, these points are 'directly' captured in the real word either as endpoints of a star of polar rays centered in the laser beams emitter or as reverse intersection of several light rays coming from the same material area (Figures 10, 11). In both cases, the process leads to a discretization of the real world's continuum much different in comparison with the voxel modelling. In fact, voxels fill up completely the 3D space as little cubes attached one to another while 3D points are like outcrops emerging from an ocean of unknown data. Is thanks to the following meshing and gap filling phases that we achieve a continuous representation of the investigated object.

Beyond these steps (voxelization for medicine, surface construction for architecture), anatomographics provide the same opportunities for both disciplines having as pivotal element the possibility of visualization, exploration and manipulation of the 3D model. In other words, they allow not only doing better what we used to do before (i.e. construct 2D representations) but above all what before was simply not possible. The opportunities that 3D models offer to medicine are quite evident especially for those structures, as the brain, that have been difficult or impossible to study using invasive methods (Figure 12). The same is

Fig. 12 Martino J et al. Neurosurgery, 3D modelling of brain structures from NMR. 2013

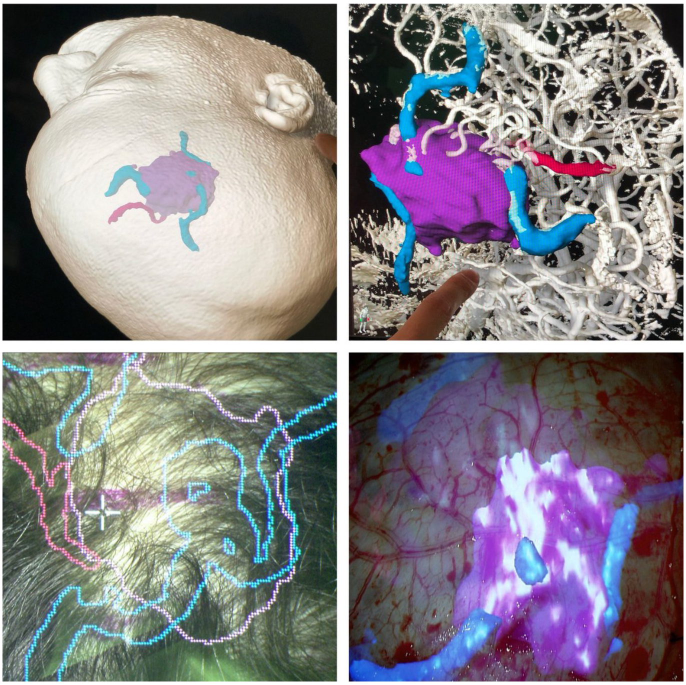
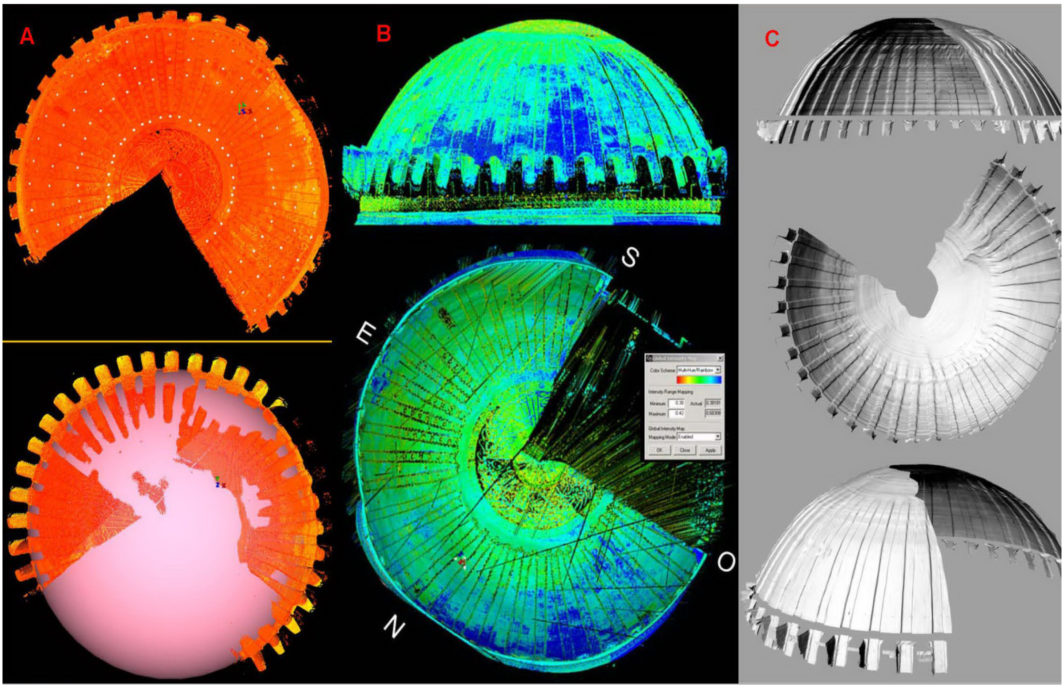


Fig. 13 Bianchini C., Haghia Sophia, surface interpolation, reflectance mapping, nurbs model.



for architecture where the possibility of considering millions of points instead of few dozens has led to more comprehensive and grounded hypothesis thanks to 3D processing (Figure 13).

A new frontier is actually in sight: data fusion. Due to their spatial consistency, 3D models are in fact increasingly becoming the geometric backbone for other information that, not necessarily spatial, can nevertheless be referred to a 3D space. The so-called Functional MRN (Figure 14) is one of the most recent examples: the anatomic structures are in this case distinguished not only with the regard of tissue typology but also of the function deployed within the same structure. Something similar pertains to the geometric positioning of diagnostic investigation for architecture (i.e. GPR, thermography, etc. Figure 15). Nowadays models are thus more and more stratified, informative and geometrically referenced.

What next then? High-end interactions using Augmented, Mixed and Virtual Reality applications: but this is another story...

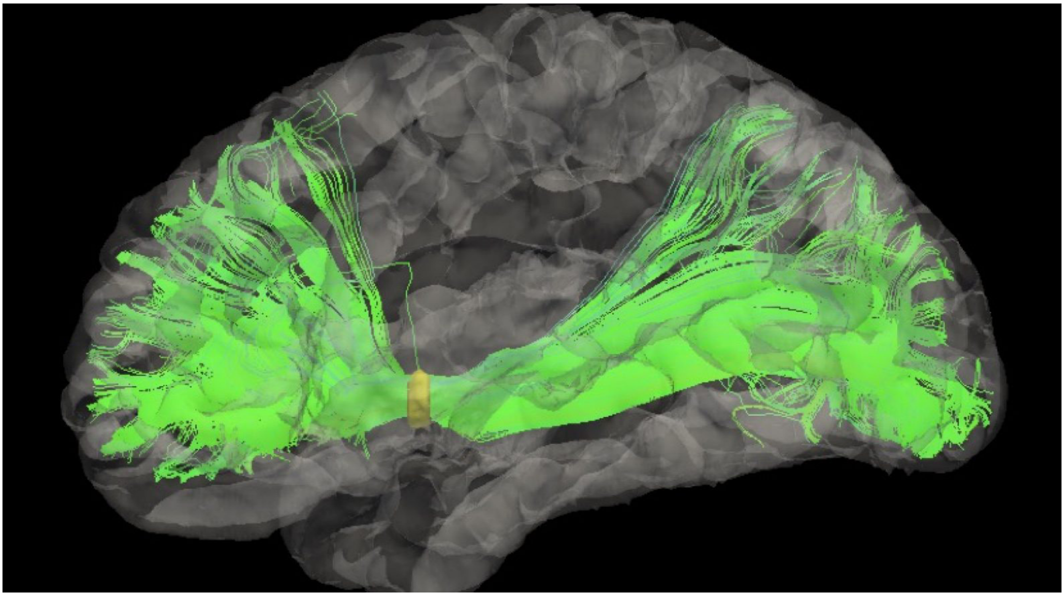


Fig. 14 Functional RNM of brain, https://www.google.com/url?sa=i&url=https%3A%2F%2Fmagazine.fbk.eu%2Fen%2Fnews%2Fbrain-cancer-patient-friendly-technology-for-a-better-quality-of-life%2F&psig=AOvVaw0uL01vWpl3lrDHLcfHTI2m&ust=1591393980651000&source=images&cd=vfe&ved=2ahUKEwjW-crYkunpAhWOP-KHQFoAL8Qr4kDegUIARCbAQ.

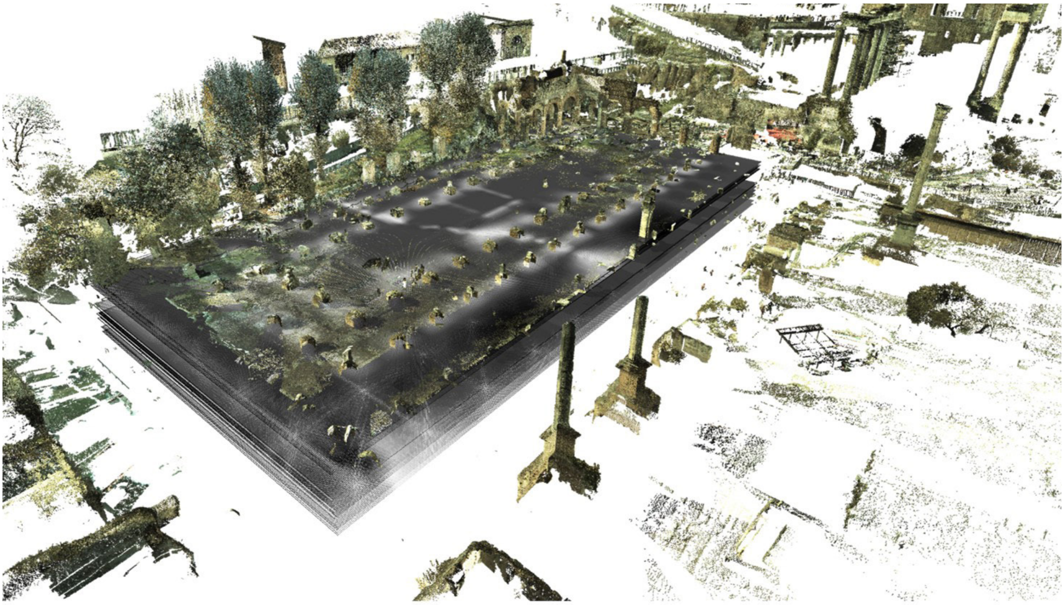


Fig. 15 Griffo M., Julia Basilica, Overlay between 3D point cloud from scanner and magnetic investigations.

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