Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2009, Valencia
Evolution and Trends in Design, Analysis and Construction of Shell and Spatial Structures
28 September – 2 October 2009, Universidad Politecnica de Valencia, Spain
Alberto DOMINGO and Carlos LAZARO (eds.)

Ivory shells and polyhedra

Tibor TARNAI*

*Budapest University of Technology and Economics
Budapest, Műegyetem rkp. 3., H-1521 Hungary
tarnai@ep-mech.me.bme.hu

Abstract

We present a morphological survey of nested ivory shells and polyhedra made by turning, and show examples of related objects of art of known ivory collections, that can be interesting from geometrical and also from structural point of view.

Keywords: Morphology, geometry, polyhedra, nested spherical shells, Chinese ball, turning, turnery art, ivory carving.

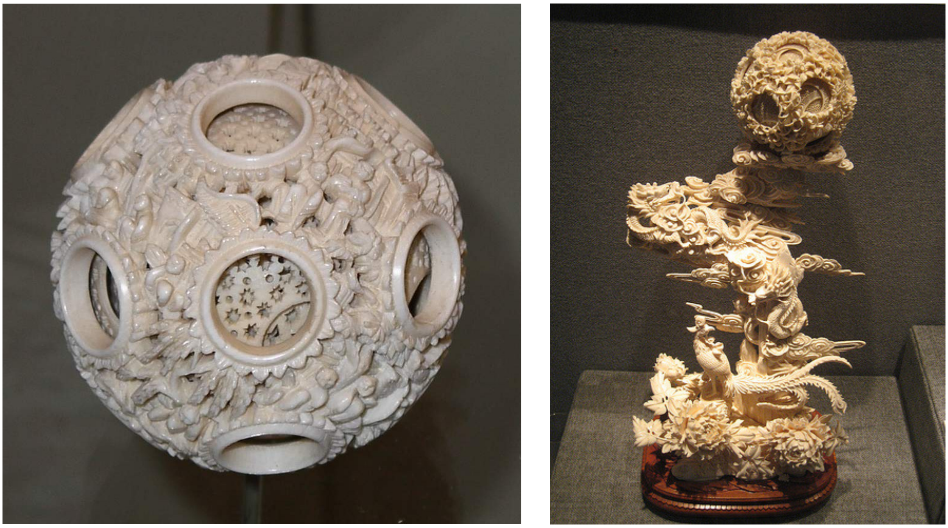
1. Introduction

Nowadays souvenir shops in China sell “devil’s work balls” or “puzzle balls”, that is, multiple spherical nested shells made of jade, sandalwood or artificial ivory (Figure 1). During the Qing Dynasty, such multi-layer balls turned on a lathe were made of ivory with piercing and rich figurative carving (Figure 2). The manufacturing technology required radially drilled conical holes whose number is 12 or 14; 12 holes at the face centres of a regular dodecahedron, while 14 holes at the face centres of a cuboctahedron. For these Chinese balls, mainly the aesthetic appearance was important, and geometry was just something necessary to it. It is little known how their making started.

Similar ivory art objects appeared in Europe in the second half of the 16th century. Their manufacturing method was developed in Germany (Tomlow [1]). The art of turning ivory was prosperous until the 18th century when with the appearance of porcelain the art of ivory carving started to decay and soon ceased to exist. Contrary to the Chinese balls, the European balls have a smooth surface and a polyhedron-like shape and their beauty came from the perfect geometry. The polyhedral form shows a high level of geometrical knowledge of the artists, and this is also why the number of applied holes is not only 12 or 14, but many more (e.g. 6, 18, 20, 24, 26, 32). Another feature is that often radial spikes come through the holes from the core of the ball, that are missing from the Chinese balls.

In this paper, we present a morphological survey of nested ivory shells and polyhedra made by turning, and show examples of related objects of art of famous ivory collections, e.g. in Dresden (Syndram [2], Kappel & Weinhold [3]), Vienna (Haag [4]), Copenhagen (Hein & Kristiansen [5]), that can be interesting also from structural point of view.

Figure 1: Contemporary Chinese balls made of jade and sandalwood with 12 and 14 holes



(a) (b)

Figure 2: Chinese balls with 14 holes, carved from a solid block of ivory, (a) a 12-layer ball, Qing dynasty, 19th century, inv. no.: AO 1906-10, British Museum, London, (b) a 43-layer ball, probably 20th century, Chen Family Temple, Guangzhou, China

2. History

Ivory carvings were among the rarities collected by princes and wealthy people in the Low Countries and Central Europe during the sixteenth and seventeenth centuries. Many of their places had a *Kunstkammer* or a *Wunderkammer* (cabinet for art or curiosities), where their treasures were displayed. The intention was to suggest the wealth and knowledge of the collector and to impress guests. That was also the age of exploration, when exotic materials and plenty of ivory were brought home from the newly discovered lands. The technique of forming ivory objects on a lathe by turning reached a high degree of complexity. French, Italian and German workshops produced thin, fascinating shapes from single blocks of ivory. Noblemen pursued turning as a hobby. Among the sovereigns who collected masterpieces of turning for their *Kunstkammer* and practiced the art themselves were Princes, Dukes, Grand Dukes, Electors, Kings, Holy Roman Emperors. They established turning chambers in their courts and invited the best turners to teach them and to produce objects for their collections. Turning was also a good tool to teach geometry.

In 1574, Giovanni Ambrogio Maggiore (1550?-1598?), an Italian turner arrived to Munich on the invitation of the Duke of Bavaria to teach William V at the lathe. A year earlier, Maggiore already turned oval ivory frames for William V, and maintained that he had invented oval turning. His technique was the base of the *rose engine* by which it was possible to produce almost any shape. As Hein & Kristiansen [5] write: *'The "rose engine" lathe was among the most outstanding products of the Renaissance. Earlier it was possible to turn objects with a circular section with a movement pointing forwards. Now it became possible to turn with continuous motion, since both the rotating cutting disc and the object could be moved forwards and backwards as well as crosswise. The individual movement was controlled by stereometric die casts, named "mandrels" or "rosettes", and by combining several die casts one could turn oval, facetted and lobed or asymmetric shapes – in brief one could produce any shape, provided that the whole form was thought out in advance. The art of turning thus combined mathematics, geometry, and training in perspective and mechanics, so that turned objects came to be symbols of man's mastery of nature. Typical examples are the so-called hollow spheres – symbols of the globe and of the pupil of the eye – often containing images of Christ and of Mary. Other variants consisted of polygonal solids, often in the shape of several concentric spheres with holes pierced by thorns.'* Maggiore turned also hollow spheres (contrefait spheres), and introduced them to the court in Munich in 1582. His technique and the hollow sphere spread fast to the courts in Dresden and Vienna and to the workshops in Nuremberg and other German cities.

The basic method of producing multi-layer sphere or polyhedron is summarized by MacGregor [6]: *'The overall form of the sphere or polyhedron is first shaped on a lathe from a solid block of ivory. The surface area is then divided up geometrically according to the number of perforations required and the centres of the perforations are carefully marked. The piece is then remounted on the lathe in a special sleeve or chuck so that one of the marked centre-points is aligned with the mandrel and in this position a hole of appropriate size is turned out to the desired depth. Each centre-point is presented in turn and the process repeated. The perforations are normally cut so that they taper towards the centre of the body, and, if radiating spikes are required, these may be left in reserve in the middle of the perforation; alternatively, sockets for separate spikes ... may be drilled in the solid central body. Finally, each perforation is realigned in turn on the lathe and, with the aid of a hooked or right-angled gouge, the turner cuts sideways at predetermined depths to form the internal elements, each being detached in sequence starting with the innermost.'*

The method and the obtained forms are illustrated in Figure 3 taken from Bergeron [7]. C. Plumier (1701), G. Grollier II (1719), J.G. Doppelmayr (1730), Diderot and d'Alambert's Encyclopedia – using some figures of Grollier (1772), C. Holzapffel (1843) also contributed to making the method and the tools known. Multi-layer spheres usually occurred as parts of objects, e.g. decorations on the lid of a goblet as shown in Figure 4. These spheres also appeared in paintings of artists such as D. Remps and J. Valette-Penot.

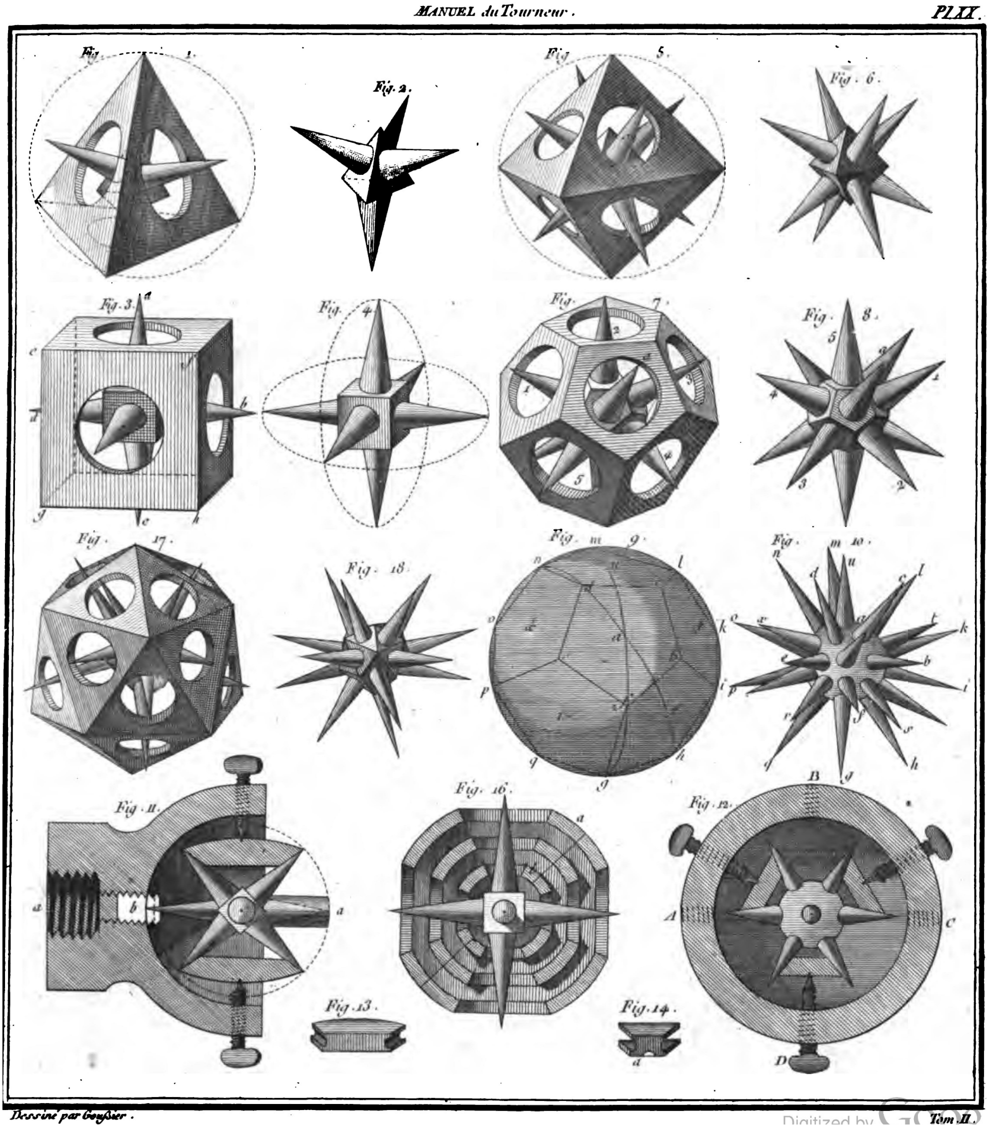


Figure 3: Turned Platonic solids. Plate XX of *Atlas* of Bergeron [7] (digitized by Google)

(a) (b) (c)

Figure 4: Turned ivory goblets, Danish Royal Collections, Rosenborg Castle, Copenhagen: (a) Inv. no. 2701, probably made in Nuremberg, 1600-1650, (b) inv. no. 2703, probably made in Nuremberg, c. 1650, (c) inv. no. 2748, goblet with crowned CA for Duke Christian Albrecht of Holstein-Gottorp, turned by Caspar Zick the elder in Nuremberg in 1685?

In the 16th, 17th and 18th centuries, a number of outstanding turner artists worked in guild workshops or in courts under the sovereigns' patronage; for instance, for a certain period Egidius Lobenigk and Georg Wecker in Dresden, Marcus Heiden in Coburg, the Zick family in Nuremberg and in Austria, just to mention some names. A list of these turners and an outline of their activities can be found on the Internet at http://ornamentalturning.net/.

The ducal and royal *Kunstkammer* pieces formed invaluable collections by the 18th century, which contained also a great number of virtuoso turned ivory objects. The surviving pieces are kept together in different museums. The largest collections are the following: the Collection of the Saxon Electors in the Grünes Gewölbe, Dresden, Germany (GG Dresden); the Schloss Ambras Collection of the Habsburg Emperors in the Kunsthistorisches Museum, Vienna, Austria (KHM Vienna); the Danish Royal Collections in the Rosenborg Castle, Copenhagen, Denmark; the Medici Treasury in the Museo degli Argenti, Palazzo Pitti, Florence, Italy. Additionally, there are several private and public museums where turned ivory masterpieces are exhibited. The Tradescant Collection (MacGregor [6]) is worth mentioning, which was not a ducal or imperial collection. John Tradescant and his son were court gardeners in England, and their collection became the foundation of the Ashmolean Museum, Oxford, UK (AM Oxford), one of the first museums in Europe. We mention one place more: Musée des Arts et Métiers – Conservatoire National des Arts et Métiers, Paris, France (CNAM Paris), where a cabinet is dedicated to the art objects of François Barreau (1731-1814), the best ivory and wood turner of the time, who, with virtuosity, produced intricate and fascinating turnings such as interlaced hollow spheres.

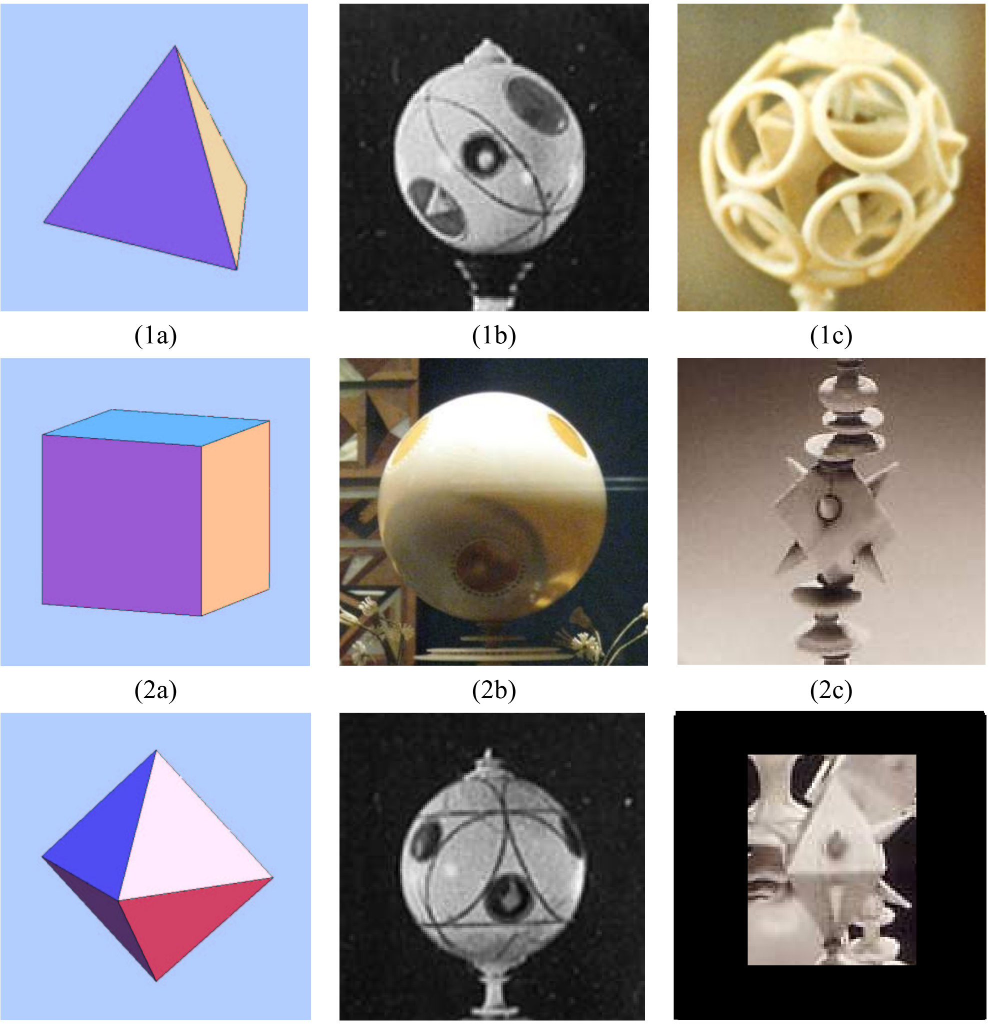
3. Geometry

Turners of the Renaissance and of the baroque era knew well geometry in general and polyhedra in particular. Several books were published on regular polyhedra and their derivatives. This is why so easy to find examples of the five *Platonic solids* among ivory turnings: tetrahedron (Figure 5(1a-c)), cube (Figure 5(2a-c)), octahedron (Figure 5(3a-c)), dodecahedron (Figure 6(1a-c)), icosahedron (Figure 6(2a-c)). If we want to identify the central solid polyhedron of a multi-layer sphere, we have to think about the fact that the faces of the polyhedron are made with a right-angled gouge. So, a face of the central polyhedron is perpendicular to the axis of the respective hole. Therefore, as a rule there is a one-to-one correspondence between the faces of the central polyhedron and the holes.

The *Archimedean solids* are solid polyhedra whose all vertices are equal but not regular, and all faces are regular but not equal. In the late Renaissance, these solids were known and, for instance, Kepler gave a complete list of them in his *Harmonices Mundi* in 1619. There exist 13 Archimedean solids (and two additional infinite classes of prisms and antiprisms) from which we could find seven among the studied turnings: cuboctahedron (Figure 6(3a-c)), truncated octahedron (Figure 7(1a-c)), rhombicuboctahedron (Figure 7(2a-c)), great rhombicuboctahedron (Figure 8(1a-c)), icosidodecahedron (Figure 8(2a-c)), truncated icosahedron (Figure 8(3a-c)), great rhombicosidodecahedron (Figure 9(a)).

The *Catalan solids* are solid polyhedra whose all faces are equal but not regular, and all vertices are regular but not equal. Catalan solids are duals of the Archimedean ones. In the Renaissance, only some of them were known. We found one Catalan solid among ivory turnings: deltoidal icositetrahedron (Figure 7(3a-c)), which is the dual of the Archimedean cuboctahedron. The fact that we could find only one is not surprising since the complete set of the 13 Catalan solids was shown by Eugène Catalan only in 1865.

The shape of the sphere in Figure 4(c) does not belong to any of the above-discussed classes. It has a vertical axis of threefold and three horizontal axes of twofold symmetry.

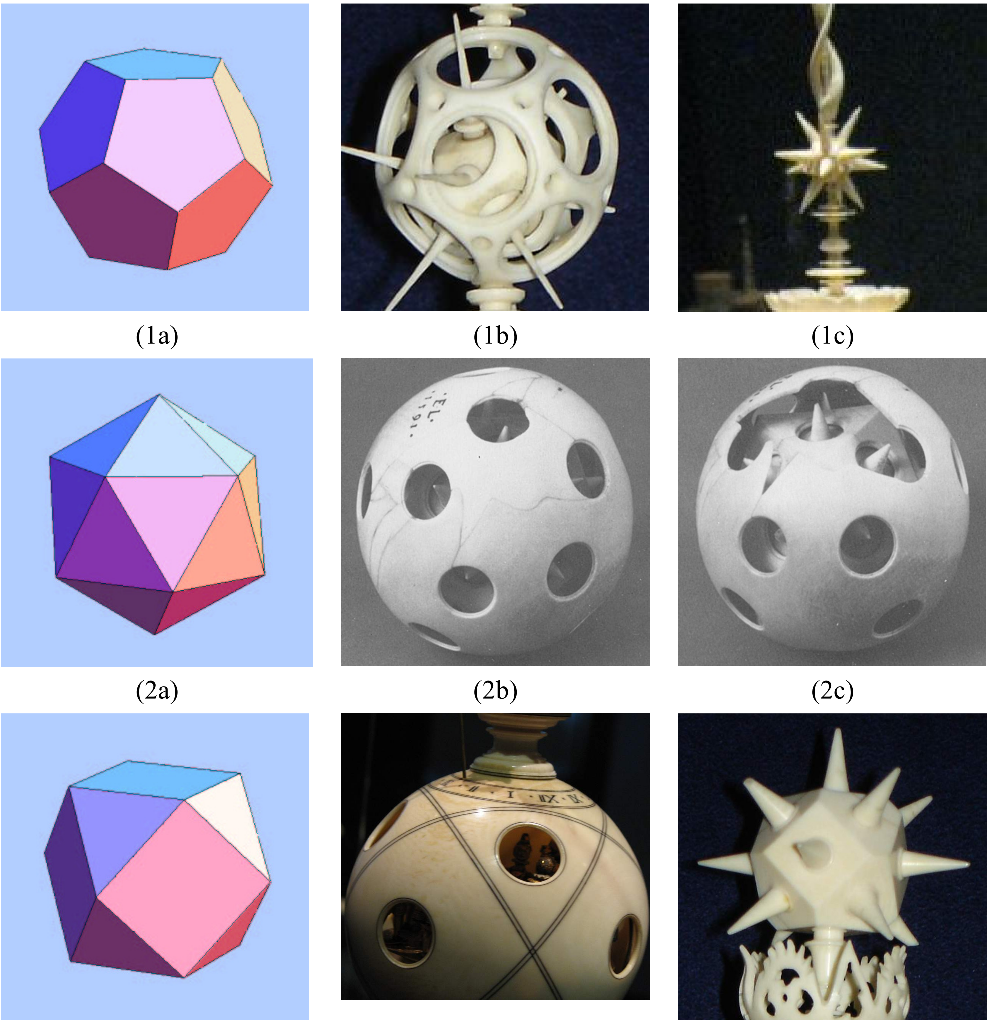


(1a) (1b) (1c)

(2a) (2b) (2c)

(3a) (3b) (3c)

Figure 5: (1a) Tetrahedron, (1b) contrefait sphere with 4 main circular openings according to the face centres of the tetrahedron, probably Dresden, (1c) spiked tetrahedron, François Barreau, around 1800, detail, inv. no. 104-23, CNAM Paris. (2a) Cube, (2b) contrefait sphere with 6 circular openings according to the face centres of the cube, detail, KHM Vienna, (2c) spiked cube, detail, probably Dresden or Nuremberg, 1st half of the 17th century, inv. no. II 284, GG Dresden. (3a) Octahedron, (3b) contrefait sphere with 8 circular openings according to the face centres of the octahedron, probably Dresden, (3c) spiked octahedron, detail of an ivory object of art, probably Dresden around 1600, inv. no. II 255, GG Dresden.



(1a) (1b) (1c)

(2a) (2b) (2c)

(3a) (3b) (3c)

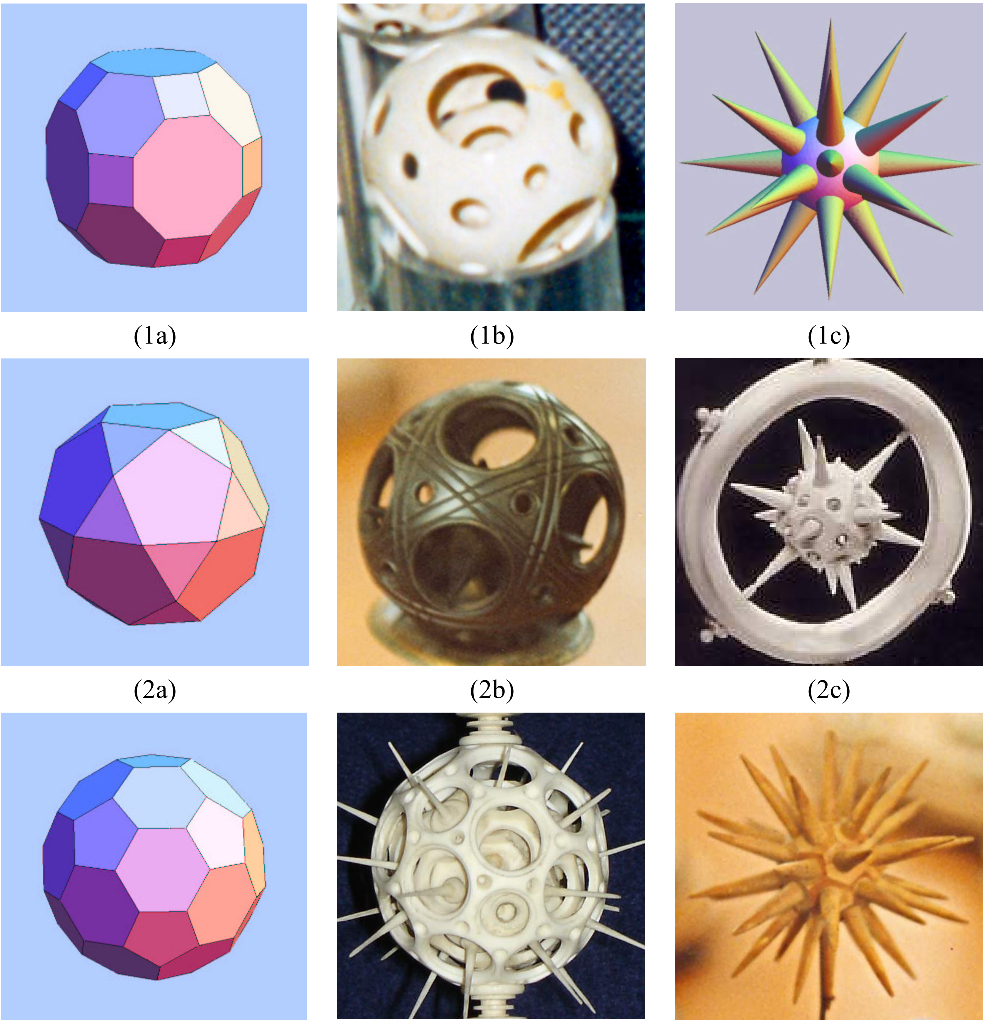
Figure 6: (1a) Dodecahedron, (1b) nested contrefait sphere with 12 circular holes according to the face centres of the dodecahedron, detail of the goblet in Figure 4(a), (1c) spiked dodecahedron, detail of a goblet, KHM Vienna. (2a) Icosahedron, (2b) contrefait sphere with 20 circular openings according to the face centres of the icosahedron, Egidius Lobenigk, 1591, detail, inv. no. II 130, GG Dresden, (2c) spiked icosahedron, inside the sphere in (2b). (3a) Cuboctahedron, (3b) contrefait sphere with 14 circular openings according to the face centres of the cuboctahedron, Egidius Lobenigk, 1589, detail, inv. no. II 133, GG Dresden, (3c) spiked cuboctahedron, detail of the goblet in Figure 4(b).

(1a) (1b) (1c)

(2a) (2b) (2c)

(3a) (3b) (3c)

Figure 7: (1a) Truncated octahedron, (1b) nested truncated octahedron with circular holes on the 14 faces, turned ivory, German, around 1650, inv. no. KK 3617, KHM Vienna; the directions of spikes on the spiked truncated octahedron are the same as that on the spiked cuboctahedron (1c). (2a) Rhombicuboctahedron, (2b) contrefait sphere with 26 circular openings according to the face centres of the rhombicuboctahedron, François Barreau, around 1800, ebony, inv. no. 104-2, CNAM Paris, (2c) approximate form of a spiked rhombicuboctahedron. (3a) Deltoidal icositetrahedron, (3b) nested contrefait sphere with 24 main circular holes according to the faces of the deltoidal icositetrahedron, Georg Friedel, 1611-1619, detail, GG Dresden, (3c) the whole cup, the upper part of which is in (3b).



(1a) (1b) (1c)

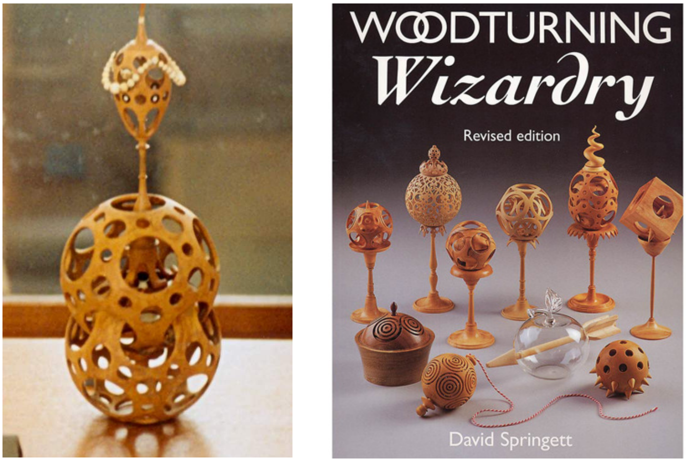
(2a) (2b) (2c)

(3a) (3b) (3c)

Figure 8: (1a) Great rhombicuboctahedron, (1b) contrefait sphere with 26 circular openings according to the face centres of polyhedron in(1a), probably German, first half of the 1600s, inv. no. Pl. CXX No. 242, Tradescant Coll., AM Oxford, (1c) corresponding spikes. (2a) Icosidodecahedron, (2b) contrefait sphere with 32 circular openings according to the face centres of the icosidodecahedron, F. Barreau, around 1800, ebony, inv. no. 104-57, CNAM Paris, (2c) spiked icosidodecahedron, detail, around 1600, inv. no. II 255, GG Dresden. (3a) Truncated icosahedron, (3b) nested contrefait sphere with 32 circular holes according to the face centres of the truncated icosahedron, detail of the goblet in Figure 4(a), (3c) spiked truncated icosahedron, F. Barreau, boxwood, around 1800, inv. no. 104-53, CNAM Paris.

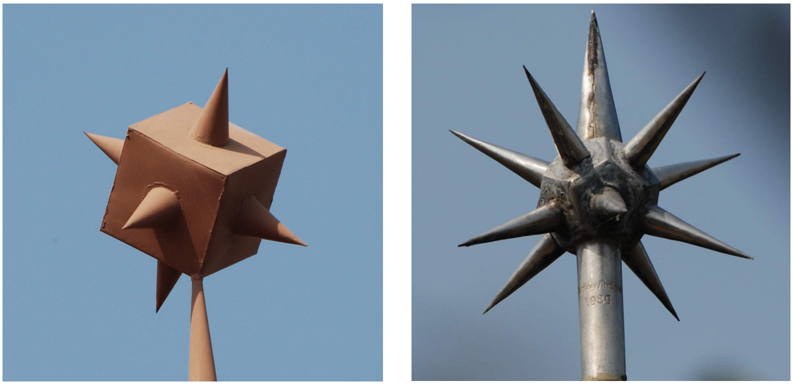
4. Conclusions

Studying ivory spheres and polyhedra made by master turners on a lathe in the 16th, 17th and 18th centuries, we discovered their geometrical background. From the studied material, in the actual turned ivory (wood) objects, we could identify five Platonic polyhedra, seven Archimedean polyhedra, and one Catalan polyhedron (deltoidal icositetrahedron).



(a) (b)

Figure 9: (a) Two interlaced hollow spheres, each with circular openings according to the face centres of the great rhombicosidodecahedron (some openings not made), F. Barreau, boxwood, around 1800, inv. no. 104-8, CNAM Paris. (b) Cover of a book by D. Springett



(a) (b)

Figure 10: Roof decorations of buildings in Budapest: (a) a spiked cube at the corner of Nagy Lajos Király Street and Erzsébet Királyné Street, (b) a spiked dodecahedron on the Reformed Church of Albertfalva at the corner of Tétényi Promenade and Nyírbátor Street

Although the art of turning ivory does not exists today, fortunately, the spirit of the Renaissance and baroque master turners survives in the activities of ornamental turning enthusiasts such as David Springett (Figure 9(b)) who is able to reproduce such an intricate piece as a pair of interlaced hollow spheres (Figure 9(a)) introduced by the French virtuoso turner François Barreau, that is difficult to think how it was produced on a lathe.

Spiked polyhedra, which frequently occurred in different turned ivory pieces, do not represent particular shapes but are natural results of the turning technology. It is worth mentioning, however, that the shapes of these spiked polyhedra survived in the "collective unconscious" of the society, and centuries later they were reborn as ornaments. For instance, the spiked cube and dodecahedron (Figures 5(2c) and 6(1c), cf Figure 3) appeared as decorations on the top of buildings in Budapest (Figures 10(a) and (b)), though their makers probably have never heard about ivory turning and never seen contrefait spheres.

Acknowledgements

I thank Dr. H. Almegaard, Prof. A. Florian, Ms. B. Kresling, Mr. S. Kabai, Dr. A. Lengyel for repeated help in preparing this paper. Photographs have been used by courtesy of the following: Henrik Almegaard: Figs 4(a,b,c), 6(1b,3c), 7(1c), 8(3b); Biruta Kresling: Figs 5(1c), 7(2b), 8(2b,3c), 9(a); András Lengyel: Figs 10(a,b). Figures 2(b), 3, 5(1b,2b,2c,3b,3c), 6(1c,3b), 7(1b,3b,3c), 8(2c) have been taken from the Internet. Figures 6(2b,2c) are details of Figs 31, 30 of Dinger *et al.* [8].

References

[1] Tomlow J. Polyhedra from Pythagoras to Alexander Graham Bell. In: *Beyond the Cube: The Architecture of Space Frames and Polyhedra*, Gabriel JF (ed.). Wiley, 1997, 1-34.

[2] Syndram D., *Gems of the Green Vault in Dresden*. Koehler & Amelang, Leipzig, 2005.

[3] Kappel J. and Weinhold U., *The New Grünes Gewölbe: Guide to the Permanent Exhibition.* Staatliche Kunstsammlungen Dresden, Deutscher Kunstverlag, 2007.

[4] Haag S., *Meisterwerke der Elfenbeinkunst* (Kurzführer durch das Kunsthistorische Museum, Band 8: Elfenbeinkunst, 191 S.), KHM, Wien, 2007.

[5] Hein J. and Kristiansen P., *Rosenborg: A Guide to the Danish Royal Collections.* (6th ed.), Rosendahls, Copenhagen, 2005.

[6] MacGregor A. (ed.), *Tradescant's Rarities: Essays on the Foundation of the Ashmolean Museum 1683 with a Catalogue of the Surviving Early Collections.* Clarendon Press, Oxford, 1983.

[7] Bergeron L.-E., *Manuel du Tourneur.* (Seconde Édition), Hamelin Bergeron, Paris, 1816.

[8] Dinger B., Kappel J. and Trommer E. eds, *Wiedergewonnen: Elfenbein Kunststücke aus Dresden, Eine Sammlung des Grünen Gewölbes.* Katalog der Sonderaustellung 2.6.-3.12.'95, Deutsches Elfenbeinmuseum Erbach, 1995.