Valerie Shrimplin, Gresham College, London

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Borromini and the Cultural Context of Kepler's *Harmonices Mundi*

Abstract

The idea of circular domed architecture as imitative of the flat earth covered by the 'Dome of Heaven' was established from Byzantine times up to its revival during the Renaissance. Yet the cosmological symbolism of the circle was replaced in the early seventeenth century as elliptical, oval or other geometrically-inspired domes became a key feature of the Baroque. The move away from circular to oval or elliptical forms by architects like Borromini might well be related to the new cosmology and Kepler's view of elliptical orbits as the basis for the structure of the universe. Building on his *Mysterium Cosmographicum* (1596) and the view of perfect, regular nested solids as the basis for the organisation of the planets, Kepler focused on the ellipse as underlying the mechanics of the universe. His realisation that the universe was not based on perfect circular motion but on elliptical orbits (with the sun at one of the foci) was developed in *Harmonices Mundi*, linked to concepts of harmony and proportion. In turn, the work of the architect Borromini (as at S. Carlo alle Quattro Fontane 1638-41 and S. Ivo della Sapienza 1642) involve novel and complex geometric designs that can be linked to Kepler's astronomical ideas. Mathematical precision underlies Borromini's seemingly extravagant schemes, and Kepler's theories might well have had a direct effect on his work. It is significant that Borromini's patron in Rome was Cardinal Barberini (later Pope Urban VIII) who was well-known for his interest in astronomy. Kepler's mathematical methodology and interpretation of the geometrical structure of the universe may have appealed to Borromini and his patrons on many levels. It cannot be mere coincidence that the use of such mathematical forms in ecclesiastical architecture comes in at around the same times as Kepler's writings.

Johannes Kepler (1571-1630) was a sombre German - a Lutheran, mathematician, geometer, astronomer, astrologer and musicologist. Francesco Borromini (1599-1667) was a flamboyant Italian, Catholic artist, architect and courtier. These two seemingly different characters lived far apart, yet their worlds collided with dramatic effect in the evolving seventeenth-century Europe. As will be argued, the writings of the former (especially the *Harmonices Mundi* of 1619)[1] profoundly affected the context of the European Age of the Enlightenment - not only in science but also in the arts and culture. Changes were specifically demonstrated by the new dynamic architecture of the age of the Baroque, especiallyby Borromini, that appear to have been related to changes in world view resulting from the writings of scientists and astronomers like Johannes Kepler.

Art and architecture, particularly religious, traditionally reflected the contemporary cosmological view of the universe, and the geometry of the universe has frequently been used as inspiration for spiritual architecture from Stonehenge and even up to the present day. The widespread use of domed architecture, for example, is a reflection of the concept of the 'dome of heaven' and the natural eye observation of the (supposedly) flat earth covered by the dome of heaven. This has been widely reflected in Judaeo-Christian art and architecture, from the mosaic-encrusted golden celestial domes of Byzantine churches to the revival of perfect circular domed architecture during the Renaissance. The decoration of such domes also often alludes to astronomical symbolism of the sphere, circle and circular motion.

By contrast, from the early seventeenth century, the elliptical (or oval) dome became a key feature of Baroque architecture, and the seventeenth century saw some remarkable developments in domed architecture, that have not really been adequately explained. While the significance of the 'dome of heaven' in Byzantine and Renaissance architecture (inspired by the perception of the universe) has

[1] Johannes Kepler, *Harmonies of the World* (trans Charles Glenn Wallis) (1939, Amazon reprint); Johannes Kepler, *Harmonices Mundi* (1619, First edition, Royal Astronomical Society Library).

frequently been emphasised, less discussion seems to have taken place about post-Renaissance developments during the Baroque period from the early seventeenth century. The preference of architects like Borromini for elliptical rather than perfectly circular or hemispherical domes appears to have been inspired by developments in astronomy in the seventeenth century. This challenged many classical and humanist precepts, such as the perfection of the circular form and it is worth considering whether the predilection for the form of the ellipse by Borromini and others might have any relationship with Kepler's realisation of elliptical orbits as the basis for the structure of the universe – as first applied to the orbit of Mars and then (by 1619), to all planets. Could it be mere coincidence that the dramatic introduction of oval/elliptical domes occurs at about the same time as Kepler revolutionised the perception of the universe and its mechanics? Might the radical changes and transition to the use of oval domes in the Baroque period have any relation to Kepler's elliptical orbits?[2] Kepler's work fundamentally changed the understanding of the mechanics of the universe, having not only an immense scientific impact (in his attempts not only to describe, but to explain the cosmos) but also on culture and world view in general.

The cosmological view of the relation between the view of the universe and art/architecture has a long history, covering the ancient classical era from the Roman architect Vitruvius in the first century BC, to the depiction of cosmology as expressed in *Genesis, Isaiah,* and the *Psalms* which laid the foundation for much ecclesiastical iconography. The concept of the Dome of Heaven is influential on church architecture from early Christian times, and particularly during the Byzantine period. A significant revival of domed architecture took place during the Renaissance that was very much linked to the religious symbolism of centrally planned churches. In the Baroque period of the early seventeenth century, however, non-circular domes (ellipses, ovals) come to the fore, with a likely relationship to Kepler's views.

The *Ten Books on Architecture* by the Roman Marcus Vitruvius Pollio (c 80 – 15 BC) were a key text for Renaissance art and well-known to architects from Brunelleschi to Michelangelo and later architects. Vitruvius significantly emphasised that it is essential for all architects to 'be acquainted with astronomy and the theory of the heavens' (Book I). He followed this with sections on astronomy, zodiac, planets, sun, moon and constellations (in Book IX), defining the 'Universe' as 'the heaven that is made up of the constellations and the courses of the stars.' The tradition of the deity(s) as inhabiting the heavens above the earth was also indicated in classical times, for example by the celestial, domed Pantheon ('all gods') in Rome built in AD 126.

Similarly, the Judao-Christian view of the universe establishes the view of the flat earth covered by the Dome of Heaven, describing, for example how God 'sitteth upon the circle of the earth' and 'stretcheth out the heavens as a curtain and spreadeth them out as a tent to dwell in' (see Genesis 1; Isaiah 40:22; cf Psalm 104; Jeremiah 10:12; Ezekiel 5:5). This view was reflected in ecclesiastical art and architecture, for example, the Temple of Solomon, Jerusalem was built in the same proportions as the known universe (I Kings 6). Later on, the illustrations in the *Christian Topography* by the Syrian Monk Cosmas Indicopleustes (6th century) clearly shows not only the view of the flat earth covered by the Dome of Heaven, but also a clear and immediate correspondence with the concept of the Last Judgment and the cosmic arrangement at the end of the world, whereby the 'good' go up to heaven and the 'bad' go down to hell, beneath the earth's (flat) surface. Examples are to be found of the traditional link between domed architecture and the view of the cosmos such as the Mausoleum of Galla Placidia in Ravenna (425), the 'hanging' domed architecture of Sta Sophia in Constantinople,

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[2] This paper developed out of previous work: Valerie Shrimplin, 'Domed Architecture: Image of the Universe', Presentation at the Second Conference on The Inspiration of Astronomical Phenomena: Malta (unpublished 1999); Valerie Shrimplin, 'Borromini and the New Astronomy', *Proceedings of The Inspiration of Astronomical Phenomena* (2003) pp. 413-422.

the Monastery at Daphne in Greece, or the domes of St Mark's Venice, which also include the story of the creation of the cosmos.

The Aristotelian view of the universe as a series of concentric spheres and orbits of the planets (and also the sun and moon) around the earth held sway during the medieval period. The Renaissance revival of perfect circular domes was first emphasised by the architect Leon Battista Alberti who focused on the perfect circles of the dome and sky - 'the vast vault of the heavens' (*De Re Aedificatoria*, 1450).[3] Interest in the perfect circular form in the Renaissance derived from platonic thought and concepts of natural perfection. The symbolism of the circle was reinforced by the neoplatonic revival since Plato described the cosmos (*Timaeus*, 33B) as 'a round in the shape of a sphere, equidistant in all directions from the centre to the extremities, which of all shapes is the most perfect'. Other examples include works by Brunelleschi (the Duomo Florence and the Pazzi Chapel); Leonardo (drawings of ovals); Bramante (The 'Tempietto'); Michelangelo (Medici Chapel, the dome of St Peter's, and the *Last Judgment* in the Sistine Chapel – demonstrated as having been influenced by Copernicus's heliocentric theory.[4]

However, some remarkable examples from the late sixteenth century increasingly demonstrate a new way of thinking, such as the design for the Campidoglio by Michelangelo (1538) which appears to resemble orbits in space – and Michelangelo was well-known for his interests in the mathematics, proportion and even musical intervals of his time.[5] Oval and elliptical (non-circular) structures/domes were also not completely unknown before the Renaissance, for example, the Colosseum in Rome (1st century CE) which was so designed in order to make it directional with no corners to trap the hapless victims. The architect Serlio (1537-1575) in his *Libri d'Architettura Book 1,* considered the oval as an approximation to ellipse, or a circle in perspective. Other sixteenth-century examples are to be found but these were often simply based on a domed square with the dome elongated along one axis.[6] It has been suggested, by Blunt, that the oval form of church in the sixteenth century was also influenced by liturgical requirements following the Council of Trent, but a relationship with the changing view of the universe also seems likely. In Rome in the late sixteenth century, the architect Giacomo (or Jacopo) Vignola (1507-73) chose an unusual rectangular shape with rounded corners for his design of St Andrea in Via Flaminia (1553), whilst the church of San Giacomo in Augusta, by Carlo Maderno (completed 1600) has a more distinctive oval shape. It is interesting to note that the architect Francesco Borromini worked with Carlo Maderno on the Church of Sant'Anna dei Palafrenieri in the 1620s, demonstrating his exposure to such novel schemes as the use of a hexadecadon.

It is sometimes difficult to distinguish between the oval or elliptical form in architecture, since the axes are often similar,[7] and the precise equation for the ellipse was not generally known until the seventeenth century.[8] By 1602, and using data obtained whilst working with Tycho Brahe, Kepler had

[3] Rudolf Wittkower, *Architectural Principles in the Age of Humanism* (London: Academy, 1997), pp. 17 and 27f.

[4] Valerie Shrimplin, *Sun-symbolism and Cosmology in Michelangelo's Last Judgment,* (Kirksville, MO: Truman State University Press, 2000).

[5] Caterina Pirina, 'Michelangelo and the Music and Mathematics of his time', *Art Bulletin*, vol 67, issue 3 (1985): pp.368-382.

[6] Peter and Linda Murray, *Architecture of the Italian Renaissance* (Norwich: Jarrold, 1971), p. 198; Anthony Blunt, *Borromini* (London: Allen Lane, 1979), p. 68.

[7] Javier Barrallo, 'Ovals and Ellipses in Architecture,' *Proceedings of X Interdisciplinary Conference of the International Society of the Arts, Mathematics and Architecture* (Columbia College, Chicago 2011), pp. 9-13; Stefano Bagliani, 'The Architecture and Mechanics of Elliptical Domes', *Proceedings of the III International Congress on Construction History,* Cottbus, Germany (2009) no pagination. http://www.bma.arch.unige.it/PDF/CONSTRUCTION_HISTORY_2009/VOL1/Bagliani-Stefano_layouted.pdf: [accessed 16 May 2019].

[8] Barrallo, 'Ovals and Ellipses', p. 12.

concluded that, although he agreed with Copernicus regarding the motion of the earth (and planets) around the sun, the observations did not fit in with the traditional concept of the basis of the universe being founded on perfect eternal circles. He at first saw the orbit of Mars as oval, and then as an ellipse with the sun at one focus (1609) – a concept that he came to see as applicable to the orbits of all the planets by the time of his Third Law of Planetary Motion as laid out in the *Harmonices Mundi*.

The construction of ovals or ellipses had been addressed by Leonardo da Vinci in his *Notebooks* (*Codex Atlanticus*, c 1510) and in architecture, where ovals were used as an approximation of an ellipse for structural reasons. The device of a string to trace an ellipse was sometimes used, as clearly illustrated by Amboise Bachot in 1598 (Fig.1). But changes seem to have taken place when Kepler came onto the scene, and especially by the 1620s and 30's.

The chronology is important so a brief synopsis of Kepler's life and work is relevant here. Born in 1571 in Wiel der Stadt near Wurttemberg (part of the Holy Roman Empire), Johannes Kepler studied theology at the University Tubingen (1589), before becoming a teacher of Mathematics at Graz (1594) where he published his *Mysterium Cosmographicum* (1596) in which he supported the Copernican view that 'the sun must be the centre of the world, symbol of God, source of light and heat, force that drives planets in their orbits'. Kepler looked to the concept of perfect regular nested solids as the basis for the disposition of the planets, as derived from Plato's *Timaeus* (53D-55C).[9] Attempting not only to describe but also to explain the universe, from this time he saw God as 'Geometer' (and Kepler himself is often depicted holding geometric dividers). Moving to Prague to be with Tycho Brahe in 1600, he made much use of Brahe's observational data and eventually became Imperial mathematician and advisor to Rudolph II in 1601. Kepler had believed in Copernicus's model based on perfect circular orbits but, using Brahe's extensive and precise observations, he could not obtain a fit with the orbit of Mars, which actually has the greatest eccentricity in its orbit of all planets except Mercury. He started to question the ancient basis of astronomy founded on circular orbits and began to consider the ellipse at the basis for his view of the universe and its mechanics.[10] His *Astronomia Nova* of 1609 and *Treatise on Motion of Mars*, 1609 saw the laying out of his first and second planetary laws, showing that the orbits were elliptical and, secondly, that they did not travel at uniform speed but swept out equal areas in equal time. The *Astronomia Nova* included the first mention of the planets' elliptical paths and the idea of their movement as being free-floating as opposed to being attached to rotating celestial spheres. In addition, the inclusion of the observation of a super-nova put paid to the medieval (and earlier) ideas about the fixed, immovable and unchanging stars. As such, the *Astronomia Nova* is a key work of the scientific revolution and change in world view at the time. Using specific astronomical data and observations, Kepler had demonstrated that the universe did not work on perfect circular motion but the orbits of the planets were elliptical, with the sun placed at one of the foci, as explained in his first two Laws. Kepler moved to Linz after the death of Rudolph II in 1612, writing his *Epitome Astronomiae Copernicanae,* (published in three volumes 1617-21). The *Harmonices Mundi* followed in 1619, laying out Kepler's Third Law (that the square of the periodic times related to the cubes of the mean distances of planets from the sun)[11] as well as covering an immense amount of musical and astrological ideas. Travelling extensively between Linz, Prague, Ulm and elsewhere, he completed the massive Rudolphine Tables in 1623. At the time of his death in 1630, his ideas had not been widely accepted (for example by Galileo 1564-42 and Descartes 1596-50) but from 1630-50, the *Epitome of Copernican Astronomy* was widely read as an astronomy textbook, and the idea of ellipse-based astronomy became increasingly well known. By the mid to late seventeenth century, in England Robert Hooke and Isaac Newton had grasped and built on Kepler's ideas, with Newton's *Principia Mathematica* appearing in 1687. It can easily be appreciated that there

[9] Plato, *Timaeus*, 53D-55C (Loeb ed.), pp. 127-133.
[10] Thomas Kuhn, *The Copernican Revolution* (Cambridge, MA: Harvard University Press, 1957), pp 217-219; Arthur Koestler, *The Sleepwalkers*, (Harmondsworth: Penguin, 1984), pp. 249-255.
[11]For a concise summary of Kepler's first two Laws (in his treatise on *Motion of Mars*, 1609) and third Law (in *Harmony of the World*, 1619) see Kuhn, *Copernican Revolution,* pp. 212f.

would have been no Kepler without Tycho; and no Newton without Kepler. He was perhaps 'the last scientific astrologer and the first astrophysicist' (Carl Sagan).

Kepler's views swiftly gained far-reaching influence not only on scientific theory but also culture and world view of the time – including the cosmological symbolism of spiritual architecture, and particularly the work of the innovator Borromini. In addition, it is significant that Borromini's patron from the time of his arrival in Rome was Cardinal Barberini (1568-44, elected Pope Urban VIII in 1623) who was well-known as a religious reformer as well as a patron of the arts. Pope Urban also corresponded with and was a supporter of Galileo. Kepler's mathematical methodology and interpretation of the universe were likely to have appealed to Borromini in many ways, particularly the belief in divine geometry ruling the formation and structure of the universe, and as the key to its understanding.

Illustrations of the *Harmonices Mundi* (RAS Library edition) and the *Astronomia Nova* show significant changes in world view in the early seventeenth century. The link between architecture and world views or cosmology has already been established above and appeared to continue as the seventeenth century progressed. Ovals were sometimes used architecturally as an approximation for the ellipse (possibly for structural reasons) and instead of neoplatonic perfect circles, interest in the revival of the platonic solids and other geometric forms became prominent (ellipses, ovals, equilateral triangles and other bodies)[12]. The *Harmonices Mundi* reinforced the idea of the orbit of every planet having the sun at one of the two foci, and it was architects like Borromini in particular who combined practical skills with this new scientific learning and culture.

Francesco Borromini (1599-1667) had led a very different sort of existence from Kepler. Born in 1599, his early years were spent in Milan as a stonemason, and from an early age he was seen as an 'artistic anarchist' expressing disorder at the same time as innovation, but with a mathematical precision underlying the apparent chaos of his designs. He was interested in the scientific ideas of the day – both cultural and humanistic aspects as well as the new learning and mathematics that were necessary for architectural schemes. The ellipse had thus scarcely been considered as an architectural form before the seventeenth century. By contrast, Borromini's elliptical domes had a mathematical and geometrical foundation, possibly with a shared source with Kepler in Plato's *Timaeus* (54E-55C). The idea of Borromini's elliptical domes as a possible allusion to contemporary astronomical theory is reinforced by evidence of interest in astronomical symbolism appearing in much of Borromini's work.

Shared sources of influence with Kepler would have included the work of Federico Commandino and Muzio Oddi (mathematicians working in Milan).[13] Moving to Rome in 1519, Borromini benefitted from the patronage of the Spada and Barberini families (working on the Barberini Palace and St Peter's with Carlo Maderno). He studied classical architecture and the works of Michelangelo, being responsible for major churches in Rome before his rivalry with Bernini and eventual suicide in 1667. Borromini's main works are listed below; his major works examined here being the churches of S Carlino and S Ivo.[14]

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[12] The Platonic associations of the regular solids with the classical elements are: tetrahedron/fire; octahedron/air, cube/earth, icosahedron/water, dodecahedron/cosmos,ether.

[13] Federico Commandino (1509-75) translated the *Conics* of Apollonius of Pergamon (c 247-205 BC) published in 1566 and used by Kepler in his consideration of elliptical orbits. Muzio Oddi 1569-1639 – architect in Milan and a probable link between architecture and mathematic theory. Simona, Michea, 'Ovals in Borromini's Geometry,' in *Mathematics and Culture II* (New York: Springer, 2005): p. 45. https://link.springer.com/chapter/10.1007/3-540-26443-4_5 [accessed May 2019].

[14] John Hatch, 'The Science Behind Francesco Borromini's Divine Geometry', *Visual Arts Publications*, (2002) vol 4, pp. 127-136.

1627	Palazzo Barberini (Carlo Maderno)
1620s	Sant' Anna dei Palafrenieri (from 1583) restorations
1623-34	Baldacchino, St Peter's, contribution to Bernini's design
1634-46	**S Carlo alle Quattro Fontane (appt'd 1634, begun 1638)**
1637-50	Oratory of S. Filippo Neri (about same time)
1643-60	**S Ivo della Sapienza (appt'd 1632, begun 1643)**
1644-55	S. Giovanni in Laterano (radical renovations)
1647	Filomarino Altar, SS Apostoli Naples (icosahedron motif)
1653	St Agnes in Agona (for Urban VIII Barberini)
1655	Collegio di Propaganda Fide (Urban VIII Barberini)
1652-53	Palazzo Spada – Galleria Prospettiva

One of Borromini's earliest contributions – to the Palazzo Barberini 1627 was an amazing helicoidal staircase, showing ideas later taken up in S Carlo. His churches of S. Carlo alle Quattro Fontane (Rome, 1638-41) (Fig. 2) and S. Ivo della Sapienza (Rome, 1642) (Fig.3) involve novel and complex geometric designs that appear to be clearly indebted to contemporary astronomical ideas, especially Kepler's interpretation of the cosmos. Mathematical precision underlies Borromini's seemingly extravagant schemes, and seventeenth-century scientific developments could also have had a direct effect on his work. While the sixteenth-century revival of the dome has been linked to the perfection of the circular heavenly orbits, evidence of interest in astronomical symbolism appears in much of Borromini's work and specific motifs (such as the icosahedron) appear to relate to Kepler's theories.

Borromini's elliptical dome in S Carlo alle Quattre Fontane (1638-41) is not simply a rectangle with rounded corners. The construction here is based on a specific and measurable mathematical schema, resulting in a complex structure of elliptic segments that dominates the entire design of the church. The enormous changes in world view, cosmology and astronomy might well have had a direct effect on this work where the plan is based on an intricately evolved geometrical diagram, which appears to attempt construction of the ellipse in a far more sophisticated way than late sixteenth-century examples where domes were (very rarely) simply elongated along one axis. By contrast, the use by Borromini of the mathematically based or elliptical dome in S Carlo alle Quattre Fontane (1638-41) is striking in its geometric and mathematical basis. Not simply a rectangle with rounded corners, the elliptical dome rests on a stretched Greek cross. The façade of San Carlo is also based on a complex system of convex and concave forms. At about the same time, Borromini was working on the Oratory of S Philip Neri (1537-50), which also significantly uses stellar and astronomical details, such as the star motifs on the finials and the astronomical fireplace. An oval music room is included in the design.

Borromini's famous church of St Ivo della Sapienza, Rome, slightly later in date at 1643-60, also involves complex celestial and terrestrial zones, as appropriate to the Church of the University of Rome, La Sapienza. At S Ivo, Borromini transformed the traditional central church plan by using a star hexagon plan extending into the dome. S. Ivo involves novel and complex geometric designs that are key to the understanding of the building. The six-point starred decoration completely dominates, while the octagonal floor decoration within this hexagonal building also recalls Kepler's nested solids, especially in the use of a border or dividing line, which also recalls Kepler's approach to polygonal forms. A star/hexagon plan, is based on intersecting equilateral triangles, forming six bays and organising the structure through its geometry as ribs lead the eye up past the stars to the vault of heaven. The hexagonal ceiling is unique, and significantly, contrasts with the floor design which uses octagonal motifs, in another reference to Kepler's cosmic geometry. Spiral designs, based on the golden section (like Fibonacci curves) are used in the tower on the exterior, expressing harmony and proportion in line with the concept of musical intervals.[15]

[15] Wittkower, *Architectural Principles*, pp. 117 and 142,

In his later works, Borromini's radical renovations at S. Giovanni in Laterano (1650/1644-55) also reflect the architect's interest in current mathematical problems, as shown by the elliptical schema on ceiling. The Filomarino Altar in SS Apostoli Naples (1635-47), was designed by Borromini for Ascanio Filomarino, a close friend of his Barberini patrons. A panel of angels making music is includes as well as significant geometrical ideas, and particularly notable is the startling inclusion of the motif of the icosahedron on the top of the altar (Fig. 4) which seems to relate directly to Kepler's theory of the solids as expressed in his *Mysterium Cosmographica*, 1596 and also in the *Harmonices Mundi* (Fig.5). St Agnes in Agona (1653) is also important since Urban VIII Barberini called in Borromini to rescue the project, giving it an elliptical basis. The Collegio di Propaganda Fide (1655), also for Urban VIII Barberini, has a complex ceiling vault with mathematical and geometric patterning, whilst the Palazzo Spada (1552-33) although not an ecclesiastical building, also demonstrates Borromini's intense interest in geometry, perspective and scientific illusion. That the meaning of these works and designs is indebted partly to astronomical ideas may further be confirmed by Borromini's cosmic approach to ecclesiastical architecture.

The role of cosmological symbolism in architecture since ancient times, and especially domed architecture, was thus well-established by the Renaissance. Borromini himself was well educated and, as a mathematician, would have been familiar with such ideas. There was a significant revival of ancient sources in Milan: the translations of Roman texts by Federico Commandino were used by Kepler, and the architect and mathematician Muzio Oddi was also based in Milan.[16] Kepler's ideas had already become widespread in Italy and as far as England. His international fame meant his works were known and the summary, *Epitome of Copernican Astronomy,* was widely read. Borromini, like Kepler, also received support from the Jesuits, and his search for harmony and proportion (as in music/intervals) appeared similar to that of Kepler. Borromini examined geometric forms in architecture in the same way that Kepler considered them as the basis of universe. 'Divine Geometry' was key in the relation between human/divine, earth/cosmos, celestial/terrestrial. Contrary to the rules of classical architecture, earth's imperfections could be organised by means of a geometrical system with divine order ruling over chaos.

Galileo also looked to a geometric interpretation of the cosmos: 'The great book of nature is written in the language of mathematics … triangles, circles and other geometry' (*Opere Il Saggiatore* p. 171), while Kepler came to realise that the Cosmos is based on ellipses rather than circles. Seeing the universe as a symbol of the Holy Trinity (with God as sun, Christ as fixed stars and the forces in between as spirit), Kepler's geometry removed mankind from the centre of universe. Borromini would have been aware of Kepler's astronomy as well as the tradition of ecclesiastical architecture as microcosm of universe. His churches have symbols of the Trinity, stars, and oval/elliptical domes that were not capricious but based on mathematics. He gave a nod to the dynamic new cosmological ideas in his architecture, for observers to interpret and understand.

As far as patronage was concerned, both Kepler and Borromini were supported by the Church and other powerful patrons. Kepler's support by the Jesuits was surprising considering that he was a Lutheran. The Barberini family also provided patronage to both Kepler and Borromini. Borromini worked as architect on the Barberini Palace, and Maffeo Barberini, elected Pope Urban VIII in 1623, had a special interest in astronomy and also supported Galileo (until 1633). He was a prominent patron of the arts and a reformer of the Church. The Spada family (including cardinals), also supported Borromini who worked on their palace, as well as being patrons of astronomy.

The effects of Kepler's *Harmonices Mundi* on art and architecture appear to have continued, especially since Kepler did not share the ancient belief that 'results should be kept secret for only revealed to initiates. Quite the reverse'; and he wrote to Maestlin (1595) 'the more others build on my

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[16] Simona, 'Ovals in Borromini's Geometry', p. 45-52.

work the happier I shall be.[17] For example, in his piazza at St Peter's, Rome Bernini chose neither a circular nor square shape as might be expected but an oval/elliptical space is defined by Bernini's colonnades to enclose the foreground space of St Peter's (1655-57) as he draws away from the accepted traditional classical forms.[18] His design for Sant' Andrea al Quirinale (1658), of a transversal ellipse intersected by a longitudinal axis defined by an imposing entrance, is similarly innovative.

Even in England under James I, to whom the *Harmonices Mundi* had been dedicated, Inigo Jones and Rubens took up the motif of the ellipse in the Banqueting House Whitehall. Influence upon Sir Christopher Wren (1632-1723) also appears possible since he was an astronomer as well as architect, and his inaugural lecture as Gresham Professor (1657) referred to Copernicus, Galileo, and the elliptical orbits of Kepler.[19] Wren also used some oval or elliptical designs in several of the churches he designed after the Fire of London (1666), such as St Mary Abchurch, 1681, and in joint designs with his colleague Robert Hooke, a co-founder of the Royal Society in 1660. The change in role and status of astronomers is reflected in the painting of *The Astronomers* by Niccolo Tornioli in the Galleria Spada, in which some identifications can be made of the astronomers depicted (Ptolemy, Aristotle, Copernicus, Galileo, and possibly Tycho, Plato and Kepler).

While the seventeenth century marks the beginning of the divisions and subsequent separation (if not 'warfare') between science and theology, the prevalence of elliptical domes at this time does seem to suggest a positive link. Borromini's patron from the time of his arrival in Rome was Cardinal Barberini, who was elected Pope Urban VIII in 1623 and had been an active supporter of Galileo himself, writing a letter to him expressing his sincere admiration.[20] As far as the new astronomy was concerned, Urban VIII showed a clear interest until his *volte face* in the 1530s, by which time the fashion for elliptical domes in the Baroque had taken hold. Borromini was not only looking back at ancient ideas (from the scriptures and classics), but also at the newest ideas. Influence did not consist of just copying ideas and illustrations from *Harmonices Mundi.* Kepler's 'Harmony of the World' can be claimed as source for a real influence on Borromini's architecture, based on the understanding and expression of the concept of Order and Harmony in the universe, through underlying geometry, and perfection. The new, revolutionary and dynamic approach as proposed by Kepler brought about a change in world view and the idea of humanity's place in the cosmos - with new attitudes, as well as new science. The seventeenth century does, in many ways, mark the beginning of the divisions between science and theology but not, it seems, as far as cosmological symbolism in Church architecture in Rome the 1530s and 40s is concerned. Borromini's use of the elliptical dome in preference to classical and humanist ideas of the perfection of the circular form, appears to be related to the changing cosmological view following the dissemination of Kepler's works, particularly the *Harmonices Mundi.* It seems unlikely to be a coincidence that that the predilection for elliptical domes in ecclesiastical architecture arrived following the publication of Kepler's great work. The exuberance of the Baroque was part of the revolutionary, new and dynamic age – yet with underlying harmony and order as ordained by God.

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[17] Field, J V, *Kepler's Geometrical Cosmology* (London: Athlone, 1988), p.189f.

[18] For example, the massive elliptical dome by Francesco Gallo, Sanctuary of Vicoforte (1st quarter of 18th century); oval-plan churches of Vienna; group in Bohemia between 1698 and 1710; Guarini design for Theatine church of S. Maria Ettinga for Prague in 1769; elliptical domes in the Po valley (first half of 18th century).

[19]Sir Christopher Wren, inaugural lecture as Gresham Professor of Astronomy: 'I must reverence for giving occasion to Kepler (as he himself confesses) of introducing Magneticks into the Motions of the Heavens, and consequently of building the elliptical Astronomy.' *Life and Works of Sir Christopher Wren, from the Parentalia or Memoirs by his Son Christopher, 1549* (p. 56) (https://archive.org/stream/cu31924015672920/cu31924015672920_djvu.txt) Cornell University Library [accessed 17 May 2019].

[20] Koestler, *Sleepwalkers*, pp. 362, 437 and 448. Blunt, *Borromini*, p. 22f. and 47 (Blunt also argues the influence of Galileo on Borromini).

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