5 The Artistic Renaissance

Every block of stone has a statue inside it and it is the task of the sculptor to discover it.

Michelangelo Buonarotti (1475–1564)

I could write a thousand pages on this chapter alone. But the history of art is not the subject of this book. Therefore, I will restrict my discussion to developments by those artists whom I think contributed substantially to the science of mechanics. The subject of Renaissance Art is such a well-researched and robust subject that I fear I shall be castigated by plenty of detractors. Nonetheless, to avoid this topic altogether would be even more remiss. Thus, here are my views on the Renaissance artists who helped to advance the science of mechanics (Figs. 5.1, 5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, 5.14, 5.15, 5.16, 5.17, 5.18, 5.19, 5.20, 5.21 and 5.22).

Sometime around the beginning of the fourteenth century there was a rapid growth in economic affluence on the Italian peninsula. As is often the case, when there is wealth, there is also a proclivity to show off. The new-found wealthy in Italy wanted to demonstrate their importance, thus they hired marketers, which at the time were actually artists, usually painters, but also often sculptors.

Giotto

I consider Giotto di Bondone (1266–1337) to be the father of the Artistic Renaissance. Sometime shortly after the turn of the fourteenth century, when no one was aware that the Renaissance was poised to burst onto the Italian landscape, Giotto began painting in a new-found style that was possessed of so much more realism than that of his immediate predecessors that there is a clear dividing line between pre-Giotto and post-Giotto art in Western Europe. His teacher, Cimabue (c. 1240–1302), the last of the great medieval artists, had attempted to open this door, but had fallen just short.

It was left for Giotto to open this door full wide, and so he did. Giotto's masterpiece is the Scrovegni Chapel in Padova, completed in 1305 (make your reservations to see the chapel well in advance!). Giotto is also believed to have painted many of the frescoes in the Basilica of San Francesco in Assisi, but we

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Fig. 5.1 A possible self-portrait of Giotto, Basilica of Santa Croce, Florence

cannot be sure of this. His departure from the old Byzantine style, thus depicting scenes with realism, is a milestone in the history of art. In so doing, Giotto also paved the way for more the more precise treatment of mechanics. Within a few short years it became possible to utilize the techniques deployed by Giotto in his artwork to depict the motions of bodies much more accurately than had been heretofore possible.

One thing we can be sure of is that Giotto designed the Campanile for the Santa Maria del Fiore in Florence. This harmonious edifice is a masterpiece of structural mechanics. But far more importantly, the bell tower was a means of transporting time to the masses. Toward the beginning of the fourteenth century this ingenious means of denoting the time of day had just sprung upon the western world. And it should go without saying that a ringing bell is an application of the science of mechanics.

When a bell is struck by a hammer the bell vibrates in resonance, producing a tone that depends on the dimensions and material properties of the bell (see Chladni's experiment in Chap. 9). Typically, the larger the bell, the more energy it takes to produce a sonorous tone. Thus, mechanical devices are often constructed that rotate the bell with a mechanical pulley assembly so that the striker hits the bell with enormous energy. The motions of the surface of the bell in turn jostle the molecules in the surrounding air, thus producing a mechanical acoustic wave that is capable of propagating over very long distances (although it tends to be mitigated by wind and moisture in the air), thus making it possible to transmit the time

Fig. 5.2 Cimabue's Maestà, Uffizi Gallery, Florence

of day to the entire population of a town, thereby allowing for significantly more efficient utilization of time. Thus, we find that the use of mechanics once again drives the advance of technology.

Clock Towers

This seems to be a good point for an interesting diversion. I am speaking of clock towers, which seem to have arisen in full force around the time of Giotto. Actually, clock towers go all the way back to ancient times, when sundials were displayed on the Tower of the Winds in Athens. However, I am speaking here of clock towers that contained mechanical devices for measuring time. These seem to have sprung up in the latter part of the thirteenth century [37].

Perhaps the first such device was utilized on the tower at Westminster in London in 1288. Unfortunately, the devices used at that time supplied energy to the mechanism via hanging weights, and for this reason they kept such poor time that they had to be adjusted several times a day in order to remain accurate (they were usually compared to a more accurate clepsydra). Nevertheless, these large towers

Fig. 5.3 Giotto's Lamentation (The Mourning of Christ), Scrovegni Chapel

became the primary means for townships to keep time during the Renaissance. Finally, in the mid-seventeenth century Christiaan Huygens (1629–1695) expanded on Galileo's concept of the pendulum to design clocks that kept excellent time (except on ships, see Chap. 8). Huygens would go on to make great advances in a variety of scientific fields, many of them dealing with mechanics.

Thus, we see mechanics once again driving technology through the ever improving measurement of time, and by the middle of the seventeenth century pendulum mechanisms were being used in clock towers across Europe.

Brunelleschi

Let's get back to our story of the Renaissance. One surely singular event toward the middle of this period that hastened the rebirth of science was the construction of the dome of the Santa Maria del Fiore in Florence in 1420–1434 by Filippo Brunelleschi (1377–1446) [38, 39].

There is a story that Brunelleschi was so distraught at having lost the competition for the doors of the Baptistery in 1401 to Lorenzo Ghiberti (1378–1455) that he took a long trip to Rome with his young friend Donatello (c. 1386–1466). There the pair undertook to study the Roman ruins in great detail. Some even say that they were the first in modern times to study the ancient Roman ruins in any scientific way.

Fig. 5.4 Giotto's Campanile adjacent to the Santa Maria del Fiore in Florence

Fig. 5.5 The tower of the winds in Athens. *Note* the Acropolis in the background

At any rate, history records that Brunelleschi studied the Pantheon in particular because he was aware that the *Signoria* in Florence would eventually be forced to deal with the gaping hole in the center of the Santa Maria del Fiore. You see, the

Fig. 5.6 Portrait of Christiaan Huygens

plans had been created with the thought of building a dome above the altar, but no one had yet figured out how to construct it. Arnolfo de Cambio had actually constructed a model in 1296 for an octagonal dome, and it stood for more than a century in the side aisle of the great cathedral, but as yet no one had come forth with an executable plan of construction.

Thus armed with his understanding of the Pantheon, Brunelleschi was ready when the contract for the dome was advertised many years later. Amazingly, he proposed that he could build the octagonal dome using masonry and without the necessity of using falsework, something that had never even been considered. Everyone at the time thought that a dome was like an arch, and arches required that falsework be placed beneath the arch, only to be removed after placement of the keystone in the center of the arch.

Somehow, Brunelleschi had gleaned from his study of the Pantheon that no such falsework would be necessary when building a dome. Brunelleschi apparently posited that building falsework would necessarily require cutting down all of the available timber in Lombardia. At least in part on the basis of this, the contract was

Fig. 5.7 Photograph of the Clock Tower in the Piazza San Marco, Venice

awarded to Brunelleschi, and he was subsequently proven correct. This feat was an amazing demonstration of the power of mechanics.

The development of mathematical models for elastic bodies 400 years later (see Chap. 10) would confirm Brunelleschi's prescience. We now know that the stones do not collapse in a dome during construction due to a component of stress called hoop stress. Furthermore, the hoop stress can be broken down into two components, one of which is lateral to the alignment of the stones. This component of hoop stress keeps the stones from collapsing inwards, somewhat similar to the concept of an arch except that in this case the arch is turned on its side (see Chap. 3). Unfortunately, this component of the hoop stress also forces the structure radially outwards. Brunelleschi dealt with this problem by building a double dome—a dome within a dome, as it were, and he constructed several stone and wooden tension rings at ascending levels within the dome so that the dome would not collapse outwards. His octagonal double dome design also spanned the shape of a circle, thus ensuring that it would be structurally sound.

Brunelleschi also designed and constructed massive and complex mechanical devices for both raising the stones and bricks used to build the dome to their lofty positions, and these were powered by oxen. Some of these amazing mechanical devices are considered today to be Brunelleschi's greatest contribution to the

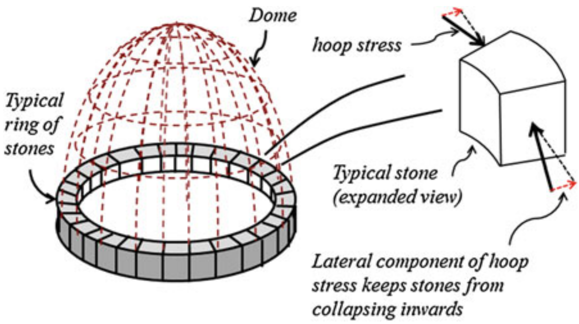

Fig. 5.8 Depiction of a Dome. *Note* the lateral component of hoop stress that keeps the stones from falling inwards

Fig. 5.9 The Brunelleschi Dome in Florence. *Note* the *octagonal shape*

Fig. 5.10 Bust of Brunelleschi in the Santa Maria del Fiore

Fig. 5.11 Da Vinci self portrait

Fig. 5.12 Da Vinci's last home, the Clos Lucé, in Amboise, France

advance of technology. By conceiving of this design and demonstrating experimentally that it would allow construction of the dome without false work, Brunelleschi advanced the science of mechanics significantly.

Fig. 5.13 Painting by Jean Auguste Dominique Ingres depicting Leonardo Da Vinci on his death bed at the close Lucé, Held in the arms of the French King François I. *Note* that this is the first room entered by visitors to the Clos Lucé

Fig. 5.14 Photo of Chambord, the largest Chateau on earth

Brunelleschi is also known to have constructed two complex paintings designed to demonstrate the concept of linear perspective, which was in infancy at that period of time. He constructed a painting of the Florence Baptistry and cut a tiny hole within it at the point of perspective. The viewer was then entreated to face the baptistery and look through the tiny hole from the backside of the painting. A mirror was then held up beyond the painting, and the viewer was able to see the painting through the mirror. When the painting and the mirror were removed, the viewer saw exactly the same view (the actual baptistry) before him/her, thus demonstrating the concept of linear perspective. Although these two panels have

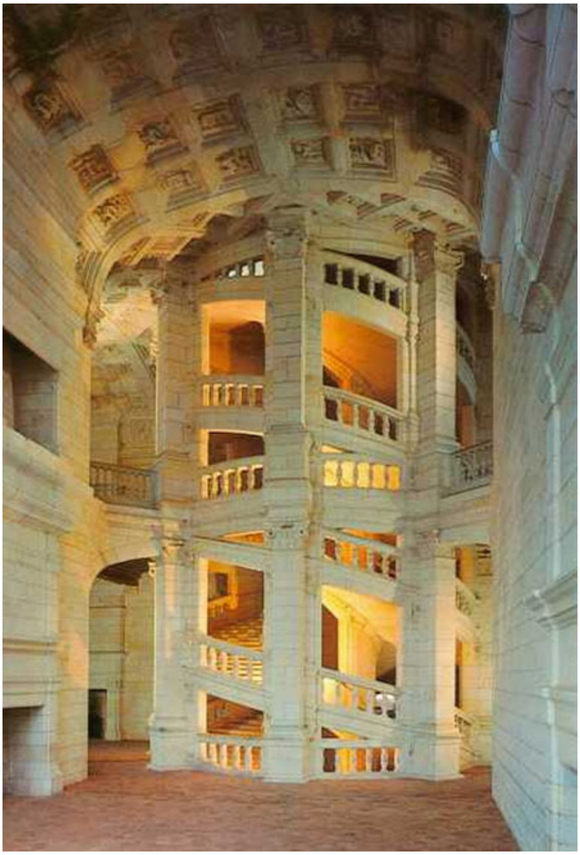

Fig. 5.15 Leonardo's double helix staircase at Chambord

been lost, Brunelleschi is therefore claimed by some to have invented the principle of modern perspective (although Ambrogio Lorenzetti (1290–1348) is known to have previously painted the Annunciation in 1344 with proper perspective), a necessary tool in mechanics. Subsequent deployment of this technique proved invaluable to the science of mechanics.

There is a story that the *Signoria* did not believe Brunelleschi when he claimed that he could build the dome without the use of false work, so he purchased a wagon load of turnips (or maybe it was rutabagas) and constructed a scale model that was large enough to walk inside in downtown Florence. If this story is true, I will bet this little dome must have become quite rancid after a few days. But the truth is, this story is almost surely a hoax, since Brunelleschi constructed a scale model from wood and bricks that was placed in the Museo dell'Opera del Duomo just behind the Dome. Sadly, this model is no longer available for viewing today. Incidentally, you can also see Michelangelo's *Florence Pietà* therein, perhaps Michelangelo's last great work of art, as well as Donatello's *Magdalene Penitent*, perhaps one of the most significant forerunners of the Impressionist Era.

Fig. 5.16 Portrait of Michelangelo by Jacopinto del Conte (c. 1535)

Fig. 5.17 Michelangelo's Dome above St. Peter's Basilica. *Note* the Egyptian obelisk in the foreground

As a reward for his grand accomplishments, Brunelleschi was buried in the basement of the Santa Maria del Fiore Cathedral, where one can visit his tomb today and see his likeness on the wall, as shown below.

Fig. 5.18 Michelangelo's Pietà, St. Peter's Basilica, Rome

Fig. 5.19 The Rondanini Pietà by Michelangelo, Museum of Antique Art, Milan

If you ever visit Florence, you simply must climb the steps to the top of the dome. Therein you will find that not only did Brunelleschi build a dome, he built a dome within the dome, thereby providing both structural reinforcement and a

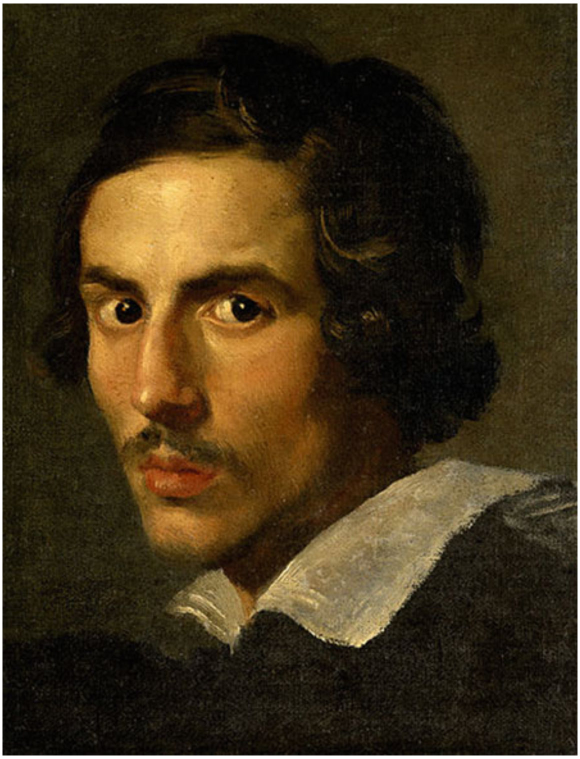

Fig. 5.20 Portrait of Bernini in the Galleria Borghese

means of ingress and egress from the lantern at the top. You will mount the stairs between the two domes, and once you arrive at the top and climb out onto the apron of the lantern, you will be treated to the most fabulous view in all of Florence.

I consider the construction of that dome to be the single most important mechanical development of the Renaissance. Not only did Brunelleschi accomplish something monumental and new in modern times, his dome was created with the help of numerous new mechanical devices designed to lift and place the bricks and stones within the dome into place at enormous heights above the city of Florence [38]. This was perhaps the greatest step forward for the science of mechanics during the Renaissance.

After the completion of the dome, a veritable construction boom began in Italy and spread outwards to the remainder of Europe. For example, the Holy See in Rome was apparently so irritated by the fabulous Brunelleschi Dome that they subsequently razed the now outdated Constantine's Cathedral in Rome and built St. Peter's Basilica. And before long, scientists were beginning to focus on producing theories capable of aiding in the design and construction of structures. Because of this, Brunelleschi is in my view the most important person of the Renaissance.

Fig. 5.21 Photo of Bernini's Colonnade in front of St. Peter's Basilica, Rome

Fig. 5.22 The Trevi Fountain in Rome, designed in part by Bernini

Da Vinci

Leonardo Da Vinci (1452–1519) was by all accounts a remarkable man, revered for his knowledge, his artistic abilities, and even his physical appearance and gentile nature in his own lifetime. His accomplishments were so broad and far-reaching that he is today considered to be the archetypal Renaissance Man. He was perhaps best known in his own time as the consummate painter, but his extant body of scientific and engineering work has demonstrated that there was practically nothing that failed to interest him. Mechanics, though it was only one of his interests, was surely one of his most passionate ones.

I've visited the reputed place of Da Vinci's birth on the hill overlooking Vinci (although in actuality no one really knows here he was born). I've also been to Da Vinci's villa in Amboise, the Close Luce, quite a few times, and I've visited his tomb at the Château d'Amboise down the hill by the Loire River. It is a fabulous place. François I, the King of France, treated him well in the last 3 years of his life. Leonardo seems to have been debilitated by a stroke during this period, so it must not have been as pleasant as could be expected for the period of time that he lived in France.

Da Vinci was an amazing polymath—a master of many different things—and he was known for it in his own lifetime. Very few scientific types have achieved such status in their own lifetime. However, he seems to have failed to transmit the predominant body of his knowledge to the public. To put it more concisely, he did not use his abilities to educate. On the contrary, as we know from his manuscripts, he was quite secretive. He went to some lengths to hide his work, writing backwards or even in shorthand quite often. As a result, much of his work lay dormant, hidden away for more than a century. In reality, most of his writings have come to the light of day only in the last 150 years or so. By that time many of his ideas were precluded by later icons. Thus, although this oversight can be forgiven as a custom during his time, Da Vinci may have missed an opportunity at a far greater immortality.

I will give you an example. Leonardo wrote the following in one of his notebooks:

> A heavy body which falls freely acquires one unit of velocity. In the second unit of time it will acquire two units of motion and two units of velocity, and so on in the way described above.

This quotation was discovered and published in 1890. A century after Leonardo's passing, Galileo wrote in his book *Dialogues Concerning Two New Sciences* [40], published in 1638:

> The spaces described by a body falling from rest with a uniformly accelerated motion are to each other as the squares of the time-intervals employed in traversing these distances.

It sounds like Galileo read Da Vinci's text a century after Da Vinci's passing and expanded on it, but Galileo was totally unaware of Da Vinci's description because it was still hidden away. If Galileo had been aware of Da Vinci's thoughts, is it possible that Galileo would have arrived at his views sooner, and perhaps even taken that additional step to the first universal law arrived at by Newton a mere 50 years later? We will never know, because the importance of Da Vinci's manuscripts was not perceived until long after his death.

In his excellent book entitled *A History of Mechanics*, René Dugas says that "Leonardo Da Vinci cuts the figure of a gifted amateur" [41]. Indeed, in his own words, Leonardo termed himself "an unlettered man" [42].

In the year 1516, now failing in health, Leonardo found himself in difficult financial circumstances. François I, the King of France, who was visiting Lombardy at the time, offered Leonardo a secure place near his palace in Amboise, France. Leonardo accepted this generous offer, thus spending the remaining 3 years of his life in the Clos Lucé, connected to the King's palace by a secret tunnel. History tells us that François and Leonardo shared many interesting conversations on a vast array of subjects before Leonardo's untimely death in 1519 [42].

Interestingly, at the time that François I ruled, France was considered to be a bit of a backwater compared to the rapidly flowering Renaissance cities across Italy. In the same year that Leonardo passed away, François began construction of a new edifice on the grounds of an old hunting lodge near Amboise called Chambord. Over the succeeding 22 years, up to François' death from a heart attack in 1547, the lodge was built into what is today the largest chateau on Earth. This was truly a massive project for that period of time in France. Anyone who has visited this magnificent chateau will immediately wonder what mechanics must have been employed to create such a formidable masterpiece.

Although we cannot be certain of this, some historians believe that Leonardo Da Vinci may in fact have been the original designer of Chambord. Whether this is true or not, we will perhaps never know. However, given Leonardo's undeniable talents, it would be nice to believe it is so, for in that case, Leonardo would perhaps be responsible at least in part for the Renaissance in France. In homage to Leonardo's possible involvement in the design of Chambord, the double helical staircase at the center of the chateau is today sometimes called 'Leonardo's Staircase'. If this conjecture is true, it would be fitting that Leonardo would have blended art and mechanics in such an attractive way.

Toward the end of the fifteenth century Leonardo, ever the dabbler, recorded what may be the first systematic attempt in history to measure the strength of a material. Leonardo writes in one of his manuscripts:

> The object of this test is to find the load an iron wire can carry. Attach an iron wire 2 bracchia (about 1.3 m) long to something that will firmly support it, then attach a basket or any similar container to the wire and feed into the basket some fine sand through a small hole placed at the end of a hopper. A spring is fixed so that it will close the hole as soon as the wire breaks. The basket is not upset while falling, since it falls through a very short distance. The weight of sand and the location of the fracture of the wire are to be recorded. The test is repeated several times to check results. Then a wire of one-half the previous length is tested and the additional weight it carries is recorded, then a wire of one-fourth length is tested and so forth, noting each time the ultimate strength and the location of the fracture.

The experiment described above has become in modern times the single most common means of measuring the so-called “elastic constants” for a material (see Chap. 9). These are a necessary input to modern models that predict the motions of solids due to externally applied loads. As such, Leonardo’s place in the science of mechanics is assured.

Michelangelo

Michelangelo Buonarroti (1475–1564) is by some accounts the greatest artist of all time. I am not an art critic, but you will certainly receive no argument from me. I have seen nearly every piece of his magnificent oeuvre. But the real question is—where does he fit into a treatise on mechanics? That is indeed a very good question that I will expand on in some detail in Chap. 9, which elaborates on the relationship between art and mechanics.

But let me at least review a few of my own observations with respect to Michelangelo, the last of the great Renaissance artists. As I have alluded to previously, there was a blurring of responsibilities of artists during the Renaissance, as evidenced most vividly by the works of one of Michelangelo’s adversaries, Leonardo Da Vinci. While Michelangelo was clearly not the polymath that Da Vinci was [43], he did nonetheless play a role in the development of mechanics.

For example, Michelangelo, expanding on the Santa Maria del Fiore dome designed and constructed by Brunelleschi, redesigned Bramante’s original design for the dome of St. Peter’s Basilica, thus forming a triumvirate of the three greatest stone/masonry domes on earth: the Pantheon, the Santa Maria del Fiore, and St. Peter’s Basilica. These three massive domes have profoundly affected all subsequent domes built on Earth.

The main reason that I have chosen for including Michelangelo in this book is due to the quote attributed to him at the beginning of this chapter. I suggest that you read the book *Michelangelo and the Pope’s Ceiling* by Ross King [43]. This treatise more than anything that I have read on Michelangelo captures the essence of this singular artist. Michelangelo, like Leonardo before him, had an obsession with perfection. And while there is no doubting the import of his two painted masterpieces in the Sistine Chapel, his sculptures are in my view the pinnacles of artistic experimental mechanics. Imagine taking a hammer and chisel and hacking away at an enormous chunk of undistinguished marble. Any school child can engage in such a practice of experimental mechanics, toying with the angle of the chisel and the force of the hammer in such a way as to produce cracks and subsequent spallation of the hunk before him/her. But to cause to emerge from this massive tangle of extremely hard and inconspicuous material something soft, ethereal, and capable of rending great emotional response is to this writer at the very pinnacle of the practice of experimental mechanics.

The first pietà (in St. Peter's Basilica) and the David are perhaps the finest examples of the mechanical arts in the history of mankind. And then there is the enormous Rondanini Pietà, the one that Michelangelo was working on when he died at the age of 88. Even this distorted work of an aged and failing Michelangelo holds enormous attraction for the mechanist within my soul.

Bernini

Gian Lorenzo Bernini (1598–1680) is not really a Renaissance artist (he came later), but he did have a profound impact on mechanics. Thus, I have included him herein. In Chap. 9 I will explain how great epochs in art precede great epochs in science. And so it is with Bernini. Spanning the lifetimes of Galileo and Newton, his baroque style of art and architecture brought breathtaking changes to the city of Rome. From the colonnade of St. Peter's Square to the fountains of Rome, the scope of his works are such as to enhance the imagination of all who see them. It is little wonder that tourists flock to every corner of Rome today in search of the masterpieces of Bernini.

Unfortunately, the experimental efforts undertaken by Brunelleschi, Da Vinci, and many others during the Renaissance did not immediately lead to significant advances in mechanics models, as most sages of that time period clung to the old Aristotelian principles, as we will see in the next chapter. Still, the impact of the experimental mechanics deployed by these artist/technologists eventually came to profoundly affect the science of mechanics.