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LEONARDO DA VINCI – PRECURSOR OF ENGINEERING DESIGN

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1. Introduction

It is common knowledge that Franz Reuleaux is recognized as the precursor of engineering design [Andreasen 2003], [Moon 2001]. In 1875 Reuleaux published a book he called 'Lehrbuch der Kinematik': *Theoretische Kinematik. Grundzüge einer Theorie des Maschinenwesens*, and in 1900 there followed a second volume called 'Lehrbuch der Kinematik': *Die praktischen Beziehungen der Kinematik zu Geometrie und Mechanik*. Long before Reuleaux there had been attempts at classifications of different machines and different kinds of machine elements. Moreover, no one had set himself the task which Reuleaux made his own, namely to outline 'a truly deductive treatment of machines'. Reuleaux viewed both strength of materials and kinematics as part of machine design. In his theory of machine development, he also pointed out the idea that both stress issues and kinematics issues had pushed the boundaries for the invention of new machines. As the first scientist he, based on mathematical and scientific fundamentals, tried to link up the generating of ideas, kinematics of machines, and engineering design into one coherent whole.

Nevertheless, in our opinion, engineering design has its precursors in the Renaissance. Such thought appeared to us during the visit to an exhibition '*Art of Invention*', organized in 2000 by the London Museum of Technology Science.

The fifteenth century saw an increased output of treatises dedicated to illustrations of machines for civil and military use. These works were inspired by illustrious classical ancestors, like Athenaeus, Philo of Byzantium, Vitruvius, Vegetius, etc. Moreover, the Renaissance abounded of brilliant persons who joined the artistic and scientific activity with the technical one. Among the most accomplished and earliest treatise-writers were Mariano di Iacopo known as Taccola - the author of excellent works '*De ingenisis*' and '*De machine*', and Francesco di Giorgio. These two Sienese artist-engineers compiled profusely illustrated texts where one observes the attempt to combine a revival of classical technology with the development of innovative methods and processes. Anyhow, the most prominent representative of the artistic–engineering community was Leonardo da Vinci.

The terms '*engineer*' and '*engineering*', appeared in these times. The first term comes from Latin word '*ingenium*' that means a stroke of mind leading to the original idea, the second comes from word '*ingeniare*' which means 'to devise'. The terms '*innovation*' and '*design*' come from Latin as well. The word '*innovare*' (*innovo, innovavi, innovatus*) means to make a innovation in, renew, restore, and '*designo*' (*designare, designavi, designatus*) means to designate, define, describe, mark out, represent [Incunabula Books 2005].

2. Manuscripts of Leonardo Da Vinci

Leonardo da Vinci was the output of that extraordinary period of human history, which was the Italian Renaissance, a period of great cultural advances and of great projects. He was a great painter, sculptor, architect, musician, engineer, inventor, and scientist. Leonardo was a perfect individual called in Latin '*uomo universale*'.

Leonardo received the usual elementary education of reading, writing and arithmetic in school. In despite of that, he had not the complete education as other sons of the rich citizens – there was a lack of Latin and Greek lessons. These defects influenced his life because he had troubles with the reading of ancient works, which set up the base for the Renaissance arts and science. On the other hand, without knowing these works, he was more open for cognition by means of his senses and for carrying out his own investigations. It was a characteristic method of Leonardo's works. His theories based mainly on results of his own research, using authority opinions to some degree only.

Leonardo's scientific and technical observations are found in his handwritten manuscripts, of which over 4000 pages have survived. It seems that Leonardo planned to publish them as a great encyclopedia of knowledge, but like many of his projects, this one was never finished. The manuscripts are difficult to read: not only did Leonardo write in mirror-image script from right to left, but he also used peculiar spellings and abbreviations, and his notes are not arranged in any logical order. After his death his notes were scattered to different libraries and collections all over Europe. To his manuscripts concerning engineering design, we can include:

- *Codex Arundel* now in the British Library in London,
- *Codex Atlanticus* kept in the Biblioteca Ambrosiana in Milan,
- *Codex Trivulzianus* held in the Biblioteca Trivulziana at the Castello Sforzesco in Milan,
- *Codex Forster* kept in the Victoria and Albert Museum in London,

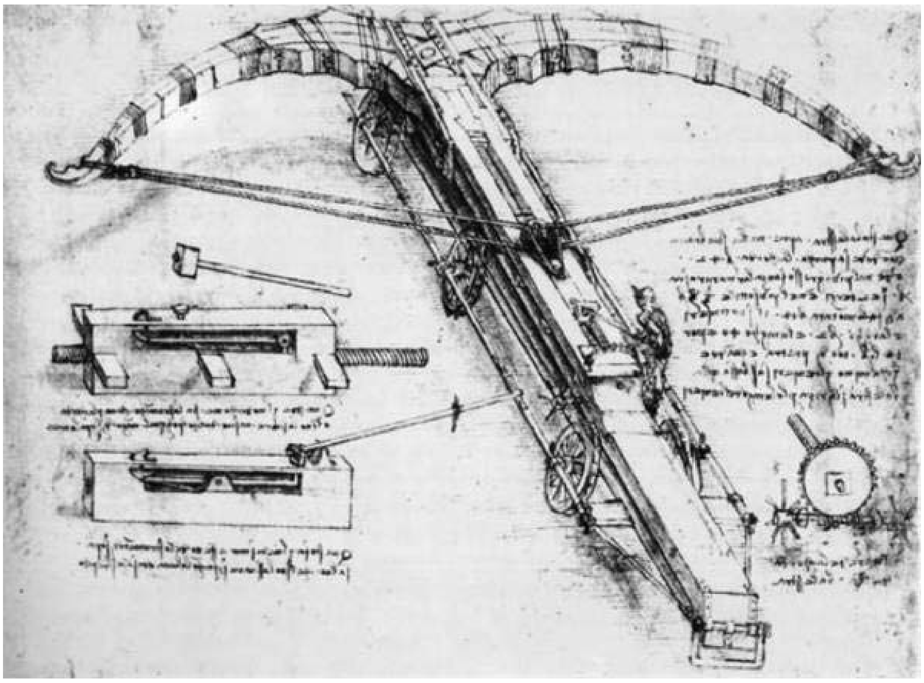


Figure 1. Gigantic crossbow, with complex loading-mechanism [Institute and Museum 2005]

- *Codex Leicester* purchased by Bill Gates in 1995,
- *Madrid Codices* kept in the National Library of Madrid.

The *Madrid Codices* were rediscovered only in 1966 and they include the most significant achievements and findings gained by Leonardo in the field of engineering design.

3. Anatomy of machines

One of the most innovative aspects of Leonardo's engineering design contribution is his analysis of the components (the ‘organs’) of machines, undertaken during the 1490s. He was the first to regard machines not as an indivisible whole, but as an assemblage of distinct parts. He was thus able to perceive that the infinite variety of machines derived from the many possible combinations of a finite number of mechanisms, which he defines as ‘elements of machines’. Leonardo planned to devote an entire treatise to these elements, in which he would have broken down machines into their basic ‘organs’ and used quantitative methods to study their characteristics and performances. He 'espiants' the organs from the machines and depicted them in isolation from the other parts to which they were functionally connected. Confirmation of his achievements in this field is his drawing presented in Figure 1, showing the gigantic crossbow, with complex loading-mechanism. The magnified components of this crossbow are clearly outlined in this drawing.

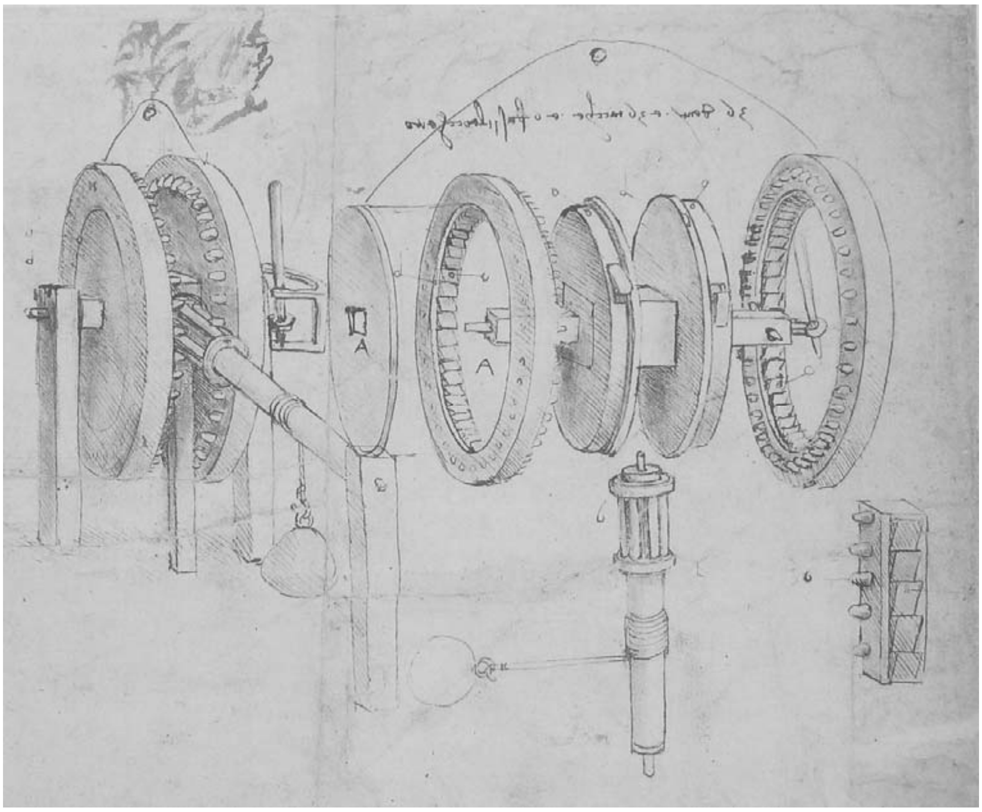


Figure 2. The two-wheel hoist in the form of an exploded view [Institute and Museum 2005]

During the same decade, Leonardo applied this method to the study of the human body, whose organs he regarded as highly sophisticated mechanical devices. He analyzed the body's articulations as semi-articulated joints governed by the laws of the lever. The routine practice of dissection exposed him to the awesome complexity of anatomical data. He was convinced that every anatomical structure has a precise function. No detail must therefore be overlooked in his visual representation. He resorted to innovative graphic devices, such as ‘see-through’ images, exploded views, drawings of the body from different vantage points, and the depiction of muscles as lines of force. The example of such an innovative visual representation is the two-wheel hoist in the form of a splendid exploded view, which reveals its basic operating components (Figure 2). The other innovative visual representation in the form of a perspective projection is presented in Figure 3.

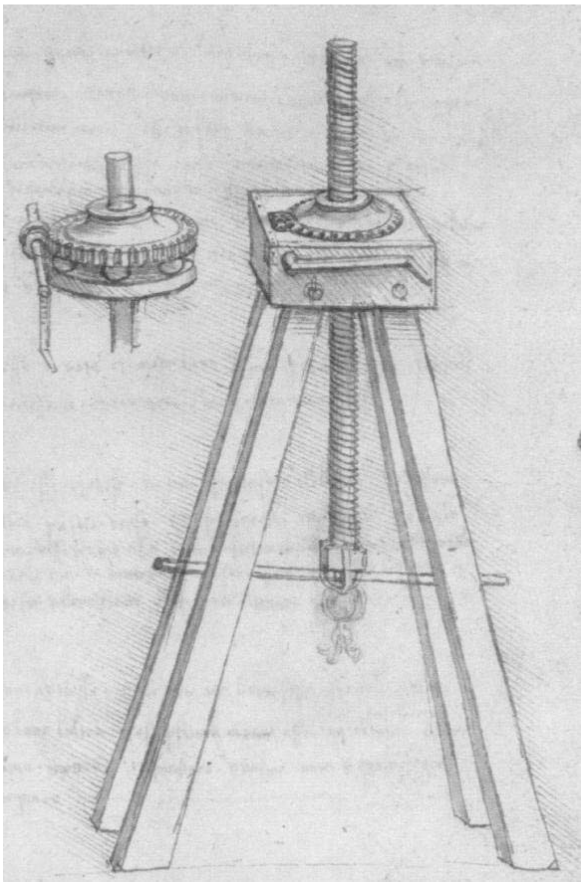


Figure 3. Perspective projection of smoother-working screw-jack [Codex 2005]

Basing on the analogy between human's body and machine structure, Leonardo studied the influence of different design features on the machine treated as a whole. As the first, he has put scientific arguments into effect driving them on the engineering path, for example: principles of building machines enabling the rational selection of design characteristics.

4. Components of machines

Many ancient machines were in common use in Leonardo's time. For example, water wheels turned millstones to grind grain and Archimedes' screws lifted water from streams providing a ready supply for drinking and washing. Artists and craftsmen in Leonardo's time knew how to build and repair the familiar kinds of machines. The idea of inventing new kinds of machines, however, would not have occurred to them. Leonardo developed a unique new attitude towards machines. He reasoned that by understanding how each separate machine part worked, he could modify them and combine them in different ways to improve existing machines or create inventions no one had ever seen before.

Leonardo set out to write the first systematic explanations of how machines work and how the elements of machines can be combined. His tremendous talents as an illustrator allowed him to draw his mechanical ideas with exceptional clarity. Five hundred years after they were put on paper, many of his sketches can easily be used today as blueprints to create perfect working models. Leonardo described and sketched ideas for many inventions hundreds of years ahead of their time and his machine designs could be broadly classified into areas of war machines, flying machines, work machines and water and land machines. However, very few of these were ever built and tested during his life.

Leonardo methodically studied the different components of machines, for instance, screws, pulleys, pulley blocks, axles, bearings, springs, cams, transmission systems, and shock absorbers. Some examples of his studies are presented in Figure 4.

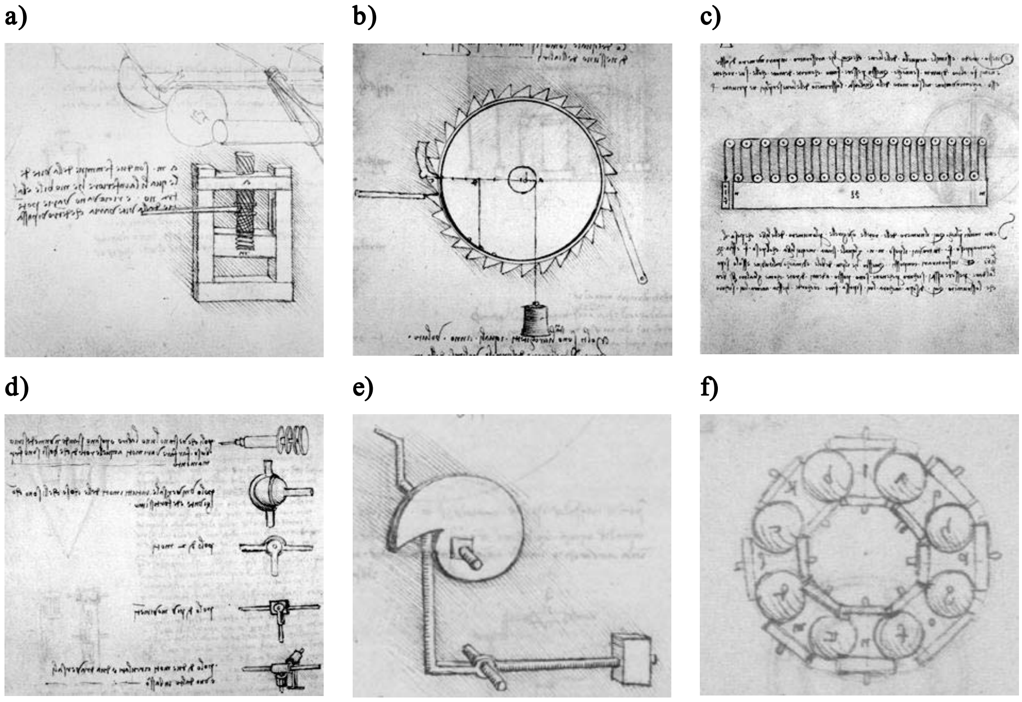


Figure 4. Leonardo's components of machines [Institute and Museum 2005]: a) differential screw, b) ratchet wheel with slanted pawl, c) block of 33 pulleys, d) various types of axle supports, e) Hammer driven by eccentric cam, f) pressure-resistant ball bearing

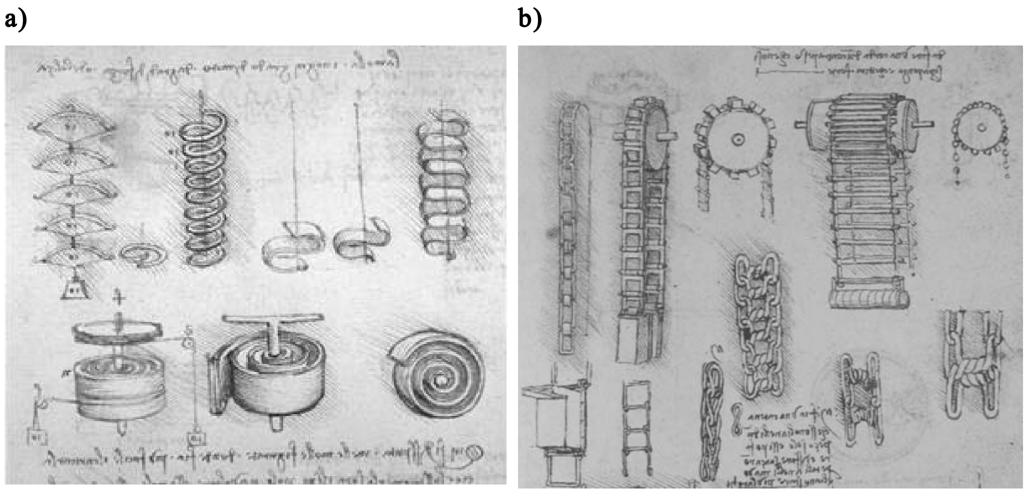
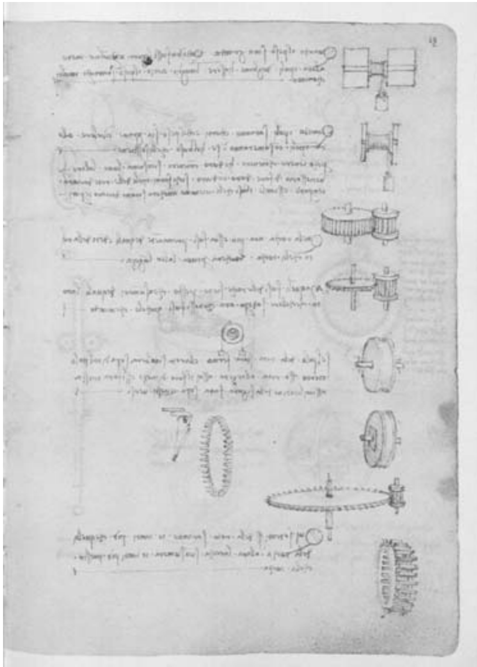


Figure 5. Classification of machine components [Zöllner 2003]: a) springs, b) chains

He also tried to classify the considered components of machines. The different types of springs and chain gears as presented in Figure 5. We should note that the presented spring classification differs from the one used nowadays in minor degree only.
In Leonardo's manuscripts, we can find proofs that Leonardo based his constructions on calculations.



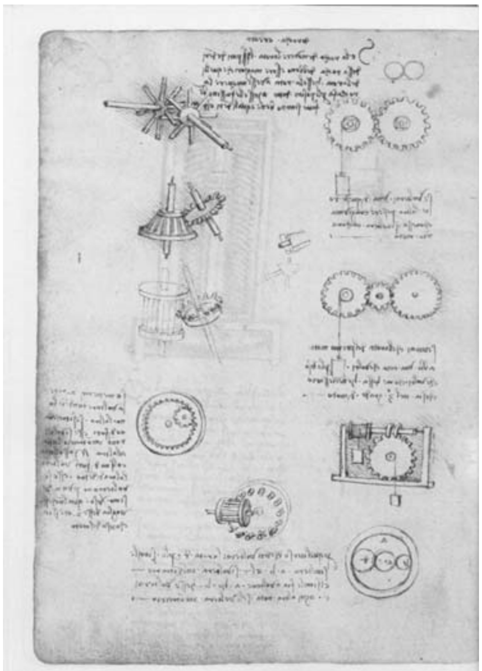


Figure 6. Pages of Leonardo's manuscripts with his searching innovative solutions [Codex 2005]

5. Design morphology

Having the brilliant gift of intuition, Leonardo aimed to increase resources of the generalized knowledge reducing the uncertainty degree in achieving the desirable result. One Results of experiment he recorded immediately and he used it next for developing new directly useful experiments. Leonardo was an unusually talented experimenter who verified his ideas in the course of accurate observations and measurements. He tried to draw general conclusions based on his observations. In the investigations carried out, he applied his own methodical approach, which could be called 'Leonardo's method'.
He registered the results of experiments with detailed accuracy. As a rule, these results were collected on one or on a few pages of his manuscripts (see Figure 6). We may say that his achievements were dissipated. Nevertheless, we could formulate the assertion that Leonardo da Vinci was a precursor of the innovative method searching new solutions by means of the so-called morphology matrix.
This assertion can be proved by his studies and achievements in the field of toothed wheels. The toothed wheel, pin-gear wheel, and pinion played a key role in technical applications of the Renaissance. Mills, machine tools, hoists, and many other devices were nearly always fitted with gears of this type. Leonardo tried to give a strictly methodical description of the nature and performance of these devices. He focused on the teeth profiles and accurately classified the different types of motion produced by various combinations of toothed wheels, pin-gear wheels and pinions.
If we try to collect his achievements in this field and distinguish his criteria of considerations, we will receive some kind of a morphology matrix. Such a matrix is presented in Figure 7. It is obvious that this matrix concerns only a small scope of Leonardo' considerations in this field. It has been set up in order to present his way of achieving innovative solutions.

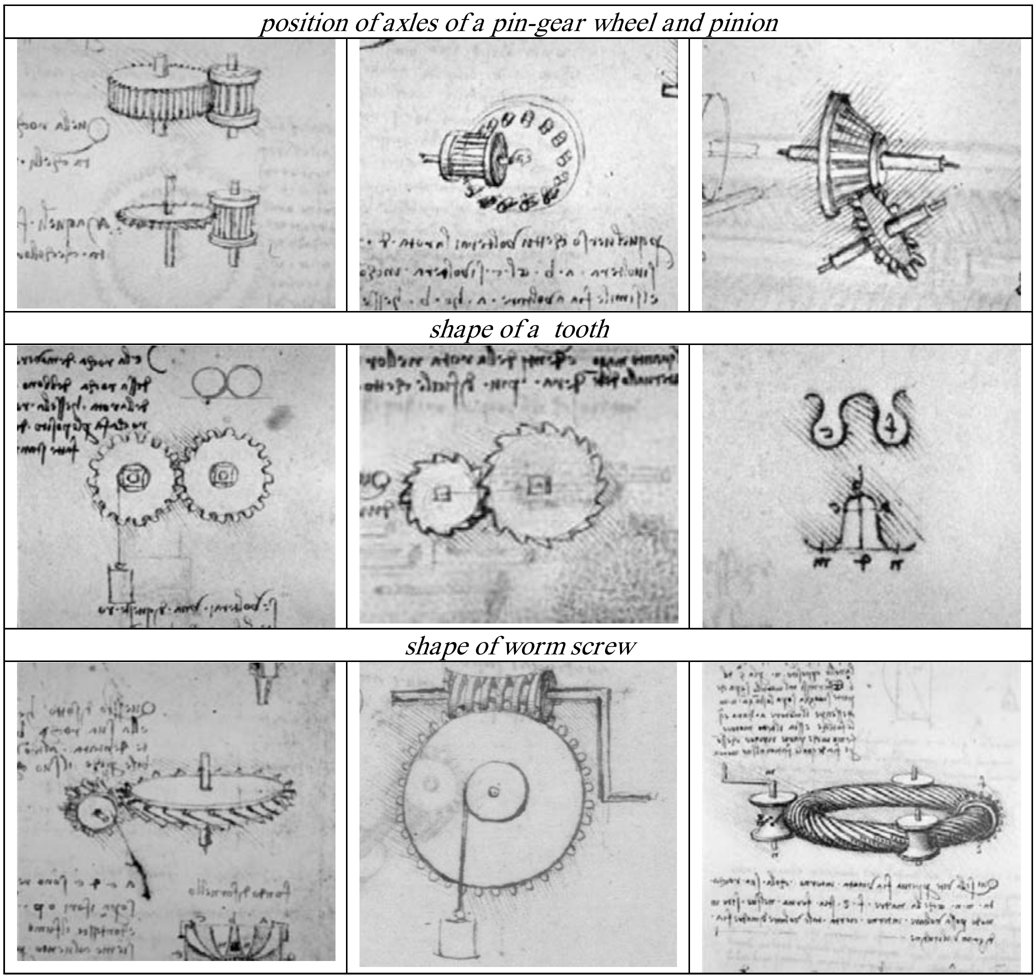


Figure 7. Achievements of Leonardo in the field of toothed wheels collected into the morphology matrix [Institute and Museum 2005]

6. Conclusion

The brief review of his accomplishments in the design as well as the analysis and synthesis of machines allows us to state that Leonardo da Vinci:

- was a precursor of the 'engineering design',
- was a scientist in present understanding of this word because he carried out systematic scientific investigations,
- that to this day, he remains one of the greatest people to ever have shadowed this earth and a great man of the arts and sciences.

Some people claim that today's progress is the domain of great corporations having gigantic financial possibilities. They tell that the times of lonely and insane scientists already have gone by. This may well be the case. Nevertheless, at the beginning of great machines there is always one stroke of the human genius. The brilliant men's creativity will not be replaced by any corporation or structure. Civilizations have better and worse days. When they rise up again after a period of decline, they always owe their renaissance to brilliant individuals and they owe their renaissance to people creating their visions in less or more unremembered laboratories paying no attention to the economic situation.

this was the case with the computer boom and with the internet euphoria even so. Today we have the new inventions and the new Leonardos pushing our world forward.

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