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The Engineering and Mechanics of Self-Propelled Vehicles from the Renaissance: The Projects of Francesco di Giorgio

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Abstract

During the Renaissance, the idea of a complex mechanical system capable of autonomous movement, a forerunner concept of our modern automobile, found its first designs and exploratory conceptualizations. In particular, it will be one of the so-called "*Sienese engineers*", Francesco di Giorgio, one of the first to systematically explore the mechanics of self-propelled vehicles as part of his studies of machines that will later become part of his *Treatise of Architecture*. Francesco di Giorgio's self-propelled machines still lack an engine and are set in motion by human power, but their mechanics are already highly sophisticated and ahead of their time. Thanks to the various manuscripts that have been preserved, his legacy in this area is still entirely available. It facilitates the understanding of the development of the projects and the attempts to design machines for practical uses, as well as the theoretical approach to engineering during the Renaissance. This comprehensive study thoroughly describes Francesco di Giorgio's systematic approach to the mechanics of self-propelled vehicles. By comparing the various projects, from the rudimentary sketches in the *Taccuino* to the more sophisticated designs in the later versions of the *Treatise of Architecture*, a clear understanding of the logical and conceptual journey that led Francesco di Giorgio to pioneer the study of motion transmission in self-propelled vehicles can be obtained.

Keywords

Francesco di Giorgio, Renaissance, Engineering, Mechanics, Self-Propelled Vehicle

1. Introduction

Francesco di Giorgio [1](1439-1501) (Fiore & Cieri Via, 1997), together with Leonardo da Vinci (1452-1519), is one of the figures that best represents the Renaissance model of universal man. He was a multifaceted artist highly sought after as an architect and military engineer (Merrill, 2015); furthermore, he was an excellent painter and sculptor (Toledano, 1987), and a humanist who undertook the translation of a complex Latin text such as Vitruvius Pollio's *De Architectura* (Vitruvius, 1999; Vitruvius, 1985). Francesco di Giorgio, following in the footsteps of Mariano Daniello di Jacopo (Taccola) (1381 - ca.1458), a source of inspiration and perhaps his mentor, explored the world of machines from a theoretical point of view. He created with imagination and inspiration a world in part virtual and yet to come, partly inspired by machines currently used in his time (Galluzzi, 1996; Galluzzi, 1991). The result is a fascinating collection of machines, studies of gears, and systems to be applied to the most diverse practical activities (Ceccarelli & Molari, 2020). Unlike Leonardo da Vinci (Innocenzi, 2020), Francesco di Giorgio organized his work in an ordered and systematic way and compiled technical proto manuals that brought the technical knowledge out of the closed artisan workshops to promote it to a common heritage. Francesco di Giorgio's manuals (Merrill, 2013) would strongly influence his contemporaries and will be the basis of subsequent *Theaters of Machines*; however, although numerous manuscript copies have been compiled, a printed copy was never realized (Reti, 1963). Over time, the work of Sienese engineers and their importance in the history of engineering gradually became less prominent and their memory slowly faded away. Their fundamental role has been recognized only in the wake of the enormous interest in Leonardo da Vinci's technical work.

The innovations in the treatises of Taccola and Francesco di Giorgio are numerous and unfold in different sectors, from hydraulics, military machinery, clock mechanics to naval engineering (Shelby, 1975). Among these inventions, an original engineering theme regards the mechanics of the self-propelled vehicle, which is at the root of the concept of the modern automobile. The very basic idea of an automobile had previously been expressed by Giovanni Fontana (1395? - 1454), who had represented a *catedram deambulatoriam* in his *Bellicorum Instrumentorum Liber* (Battisti & Saccaro Battisti, 1984) (ca. 1430) and

[1]Francesco di Giorgio (FdG) was born in Siena in September 1439, his father Giorgio Martini del Viva was an official of the City of Siena, employed in the Biccherna office (financial magistracies), with small properties in the city and country. FdG began his artistic career probably as a pupil of Lorenzo di Pietro "il Vecchietta" (1410-1480), an important artist active in Siena. Together with Vecchietta he went to Rome where he had the opportunity to study classical architecture. His training was multifaceted, as a painter, sculptor, and architect. He became one of the most highly regarded and sought-after Italian military architects of the Renaissance. In 1475 he moved to the court of Duke Federico da Montefeltro working on the completion of the Ducal Palace. Besides being an artist-engineer FdG was appreciated for his multifaceted and humanistic culture. His knowledge of Latin enabled him to produce a vernacular Italian translation of Vitruvius' *De Architectura*. The experience he gained in architecture and engineering was the basis for the *Treatise on Architecture* where he also took up and reworked designs and ideas from Taccola's treatises. FdG died on November 29, 1501 and was buried in Siena.

by Guido da Vigevano (ca. 1280-1349) who in *Texaurus Regis Francie* (da Vigevano, 1993) (1335) described a self-propelled cart set in motion by blades rotated by the wind (Innocenzi, 2019).

Among the many machine projects proposed by Francesco di Giorgio, the self-propelled vehicle is undoubtedly striking for the completeness with which the Siena architect-engineer explores the mechanics to transmit the movement. These projects represent a real transition in engineering history and will be discussed in this article. The term self-propelled has been adopted to refer to the peculiar idea of Francesco di Giorgio's vehicle designs. Strictly speaking, the different vehicles, which differ in the mode of mechanical transmission of motion and use, cannot be defined as self-propelled since they do not show any internal propulsion system. Francesco di Giorgio's machines are primarily designed to be propelled by human force rather than animal power, as indicated by the various mechanical systems. The careful study of vehicle mechanics shows, however, the design intuition of a system potentially capable of moving on its own using machine-generated force. For this reason, the term self-propelled has been used in the article to reflect the profound conceptual innovation contained in Francesco di Giorgio's designs.

2. The Sources

The designs of self-propelled vehicles by Francesco di Giorgio (Brinto, 1934) are scattered in various copies of his manuscripts (Chironi, 1991). In particular, in the *Codicetto Vaticano*, the *Opusculum de Architectura* and the *Trattato di Architettura Civile e Militare* (*Trattato di Architettura*)[2] (Scaglia, 1992; Biffi, 1997).

The *Codicetto Vaticano* (or *Taccuino* (Notebook)) (*Codex Urb. Lat.* 1757) (Merrill, 2020) by Francesco di Giorgio is an extraordinary document that allows following his thoughts and ideas in the development process of the engineering and architectural projects over a relatively long period of his life. The *Taccuino*, of very small dimensions (81 × 59 × 35 mm) gives its reduced dimension to the need to be easily put in a pocket and carried during his frequent travels. It was probably used by Francesco di Giorgio starting from 1465 until at least 1476. The initial part of the notebook, consisting of 191 sheets, contains drawings and projects taken from *De Ingeneis* by Mariano di Jacopo (il Taccola) (Prager & Scaglia, 1972) (1381-1453) and by the *Re Militari* of Roberto Valturio (1405-1475), to then incorporating more and more original ideas. The notebook, which appears as a collection of scattered notes, will be the basis used for preparing the *Trattato di Architettura Civile e Militare* (Treaty of Civil and Military Architecture) and the *Opusculum de Architectura*.

The *Opusculum de Architectura* is an 80-page Codex, now kept at the British Museum in London under the catalogue number Ms. 197.b.21, containing about

[2]First version of the Trattato di Architettura: *Codex Ashburnham* 361 (1479-1481); second version: *Codex Saluzziano* 148 (1481-1486).

two hundred illustrations and drawings of machines and fortifications. It is the first complete treatise attributed to Francesco di Giorgio, even if it does not contain any accompanying text but only a dedication on the front page to the Duke of Urbino, Federico da Montefeltro (1422-1482). The *Opusculum* should have been completed between 1475 and 1477, using the notes from the *Taccuino*, when Francesco di Giorgio moved from Siena to Urbino. The *Opusculum* contains a collection of various machines, such as pumps, mills, vehicles, construction and war machines, as well as numerous plans of fortresses; some of the machines are copies from Taccola's works. The various machines are not divided by type as in the two versions of the *Trattato di Architettura* (ref. 22 is note 2). Overall, it appears as a catalogue of machines and architectures, probably compiled by Francesco di Giorgio with the aim of showing his ability as an engineer and military architect to the Duke of Urbino to ensure his benevolence.

The *Trattato di Architettura* is another source that reports Francesco di Giorgio's designs for machines and self-propelled vehicles (Guess, 1998). The first version is probably that of the *Codex Ashburnham* 361 (Maltese, 1967; Marani, 1967; Tapinassi, 2016) (c. 1479-1481) preserved in the Biblioteca Medicea-Laurenziana in Florence, handwritten in ink and tempera on parchment. The manuscript is not autographed, and the contribution of at least two people is recognized, probably Francesco di Giorgio himself and one of his collaborators in the workshop. The sheets are divided into two columns containing illustrations accompanied by the text. It is the copy of the *Trattato di Architettura* that Leonardo da Vinci came into possession and contains his annotations to the text (Mussini, 1991) (ref. 27 is note 3). The *Codex Saluzziano* 148 (1481-1486) of the Royal Library of Turin is another non-autograph handwritten copy of the first version of the treatise (Promis, 1841; The Codex Ashburnam 361 and 148). The second version, drawn up in 1486, is instead that of the *Codex S.IV.*4 preserved in the Municipal Library of Siena and of the *Codex Magliabechiano II.I.141* of the National Library of Florence.

3. The First Studies

The machines depicted in the *Opusculum* are partly copies from Taccola and partly the development of the projects sketched in the *Taccuino*. Francesco di Giorgio uses technical drawing as an essential design tool, getting in this sense from the tradition started by his teacher Taccola. However, the quality of Francesco di Giorgio's representations of machines undoubtedly represents a significant step forward compared to Taccola (Fiore, 1978). The technical drawing of Francesco di Giorgio has nothing to envy that of Leonardo, and in many cases, it is even superior in clarity and graphic quality (Geenens & Merrill, 2024).

The drawing also becomes an instrument of communication and transmission of knowledge, a central element of the treatises on machines. In the *Opusculum*, Francesco di Giorgio limits himself to graphically representing his projects without needing to use explanatory notes. The drawing is also a fundamental

element for developing a creative path made up of successive approximations and critical exploration of the most suitable solutions. The design of machines is approached as an iterative process through which to consider different combinations up to the point of building a real library of different solutions and systems.

Francesco di Giorgio uses the same mental process in the study of self-propelled vehicles found in the *Codicetto Vaticano* and then in a more complete form in the *Opusculum de Architectura*. Using these two sources, it is possible to follow the design process and the progressive development of the idea of the automobile in Francesco di Giorgio.

The creative inspiration of Italian Renaissance architects and engineers is clearly expressed in Francesco di Giorgio's study of the mechanics of self-propelled vehicles, which is amplified by the sophisticated ability to graphically represent the projects.

Thanks to the drawings dispersed in the pages of the *Taccuino*, it is possible to follow what was the probable genesis of Francesco di Giorgio's project of a self-propelled vehicle. The projects that are scattered in the *Taccuino* are only sketches that would find their full development in the *Opusculum de Architectura*; however, they allow us to understand well the design process and the progressive development of Francesco di Gorgio's ideas about the mechanics for controlling the movement of a wheeled cart.

Between the *Taccuino*'s pages, simple sketches show three-wheeled carriages moved by manually operated gears (**Figure 1**). These studies aim to explore how to transmit motion to the wheels. Francesco di Giorgio thinks of four different solutions, a central axis that through a system of toothed wheels sets in motion only the front wheel (**Figure 1(a)**), a toothed wheel that sets in motion a front

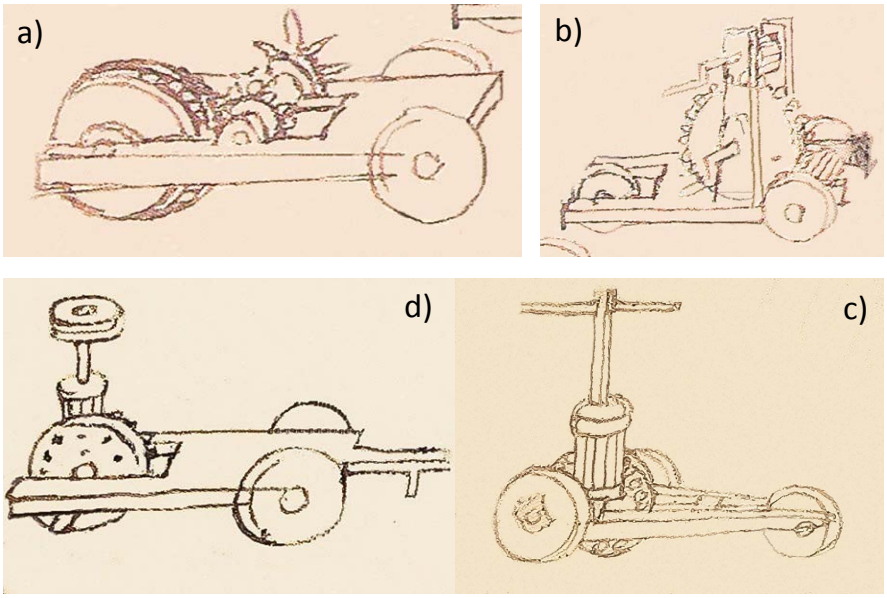

Figure 1. Three-wheeled vehicle designs set in motion through manually operated gears. Francesco di Giorgio. *Codicetto Vaticano*, (a) e (b) folio 76v, (c) folio 107r e (d) folio 107v (details). Biblioteca Apostolica Vaticana. Rome, Italy.

sprocket axle and therefore, the two front wheels (**Figure 1(b)**) and two solutions in which the traction is rear (**Figure 1(c)** and **Figure 1(d)**), with a spool that drives a single or double rear sprocket. All these systems are designed to be moved through gear wheels operated by cranks that allow the carriage to move forward and backwards depending on the direction of movement.

Francesco di Giorgio's intention is to study how to transmit motion to the wheels, in this case in three-wheeled carts. These systems are not intended to be automated, like Leonardo's famous spring-operated theatre machine project, but require external intervention to set them in motion and manoeuvre them. These sketches can probably be considered the starting point of Francesco di Giorgio's design of mechanically sophisticated self-propelled vehicles.

There are several problems faced when designing a self-propelled vehicle, such as providing movement to the system, transmission of motion to the wheels or control of direction. Francesco di Giorgio in all his designs takes it virtually for granted that the carriage is set in motion and manoeuvred by people. Some of the crew would be used to move the vehicle, others as pilots to drive it. The idea of the engine, then of a real "automobile" is left aside, and Francesco di Giorgio's attention goes entirely to developing the mechanics of the system. The Sienese engineer had clear that the system of toothed wheels could take on different configurations to transmit motion, whilst on the other hand in order to make the wheels of the carriage change direction in a controlled manner, he planned on using of an independently operated system.

Folio 115r of the *Taccuino* (**Figure 2**) shows two studies of possible steering systems to control the direction of the vehicle's motion, using a crank that on

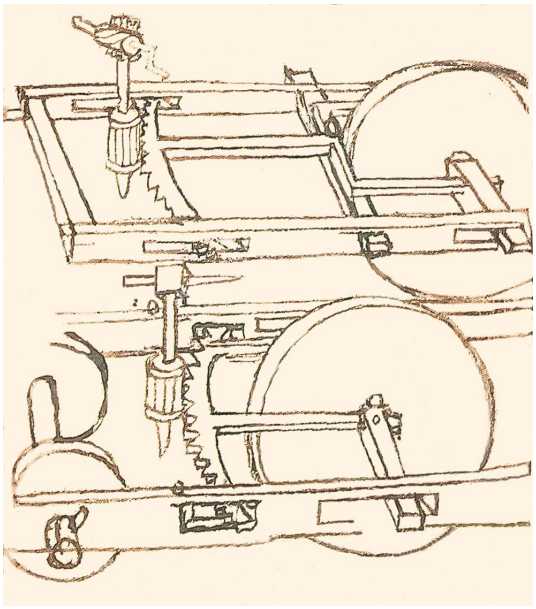

Figure 2. Study of a steering system to control the direction of the vehicle movement. Francesco di Giorgio. *Codicetto Vaticano*, folio 115r (detail). Biblioteca Apostolica Vaticana. Rome. Italy.

turn moves a spool that transforms the vertical movement into a horizontal one. The curvature of the gear wheel section allows the wheels to turn thanks to two grooves on the lateral axials. The drawing is only sketchy and was likely used to study how to use a steering wheel to turn the rear drive wheels.

Another image, also this one nothing more than a simple sketch, shows how Francesco di Giorgio thought of building the self-propelled vehicle in its final version (**Figure 3**). Starting from this simple idea, the vehicle would appear in the most advanced projects with an increasingly complex structure. In the projects that he will present to the Duke of Montefeltro through the drawings in the *Opusculum de Architectura*, shows the mechanical structures inside a "box", in a graphic visual mode that represents a kind of Francesco di Giorgio's trademark.

4. The Self-Propelled Vehicles in the Opusculum de Architectura

In the *Opusculum de Architectura*, Francesco di Giorgio's projects are also represented through a graphic method that uses perspective and orthogonal projections (**Figure 4**).

The self-propelled vehicle is shown in its complete form as an open frame through which it is possible to observe and understand the functioning of the mechanical parts. The three-dimensionality of the design facilitates the comprehension of the operation of the machine. The self-propelled vehicles are set in motion and steered through two crankshafts manually operated from the roof. Two separate systems are used to spin the drive wheels and change direction, operated by two or more men whose movement requires considerable coordination. For example, in the project in folio 3r (**Figure 3(a)**), the system provides two drive shafts for the two drive wheels and two for controlling the change of

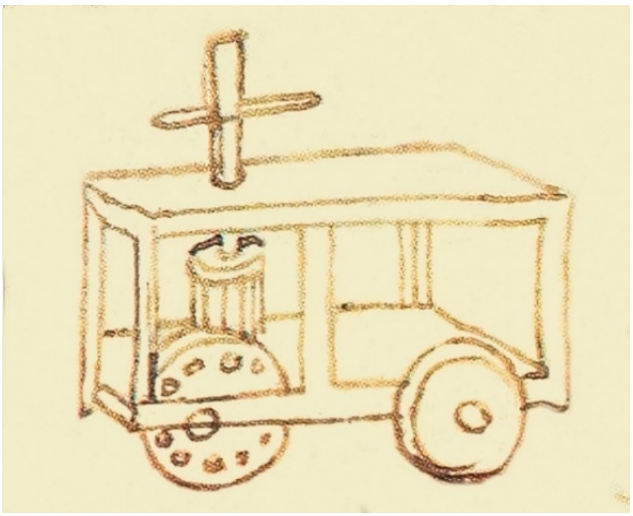

Figura 3. Sketch of a self-propelled vehicle. Francesco di Giorgio. *Codicetto Vaticano*, folio 107v, (detail). Biblioteca Apostolica Vaticana. Rome. Italy.

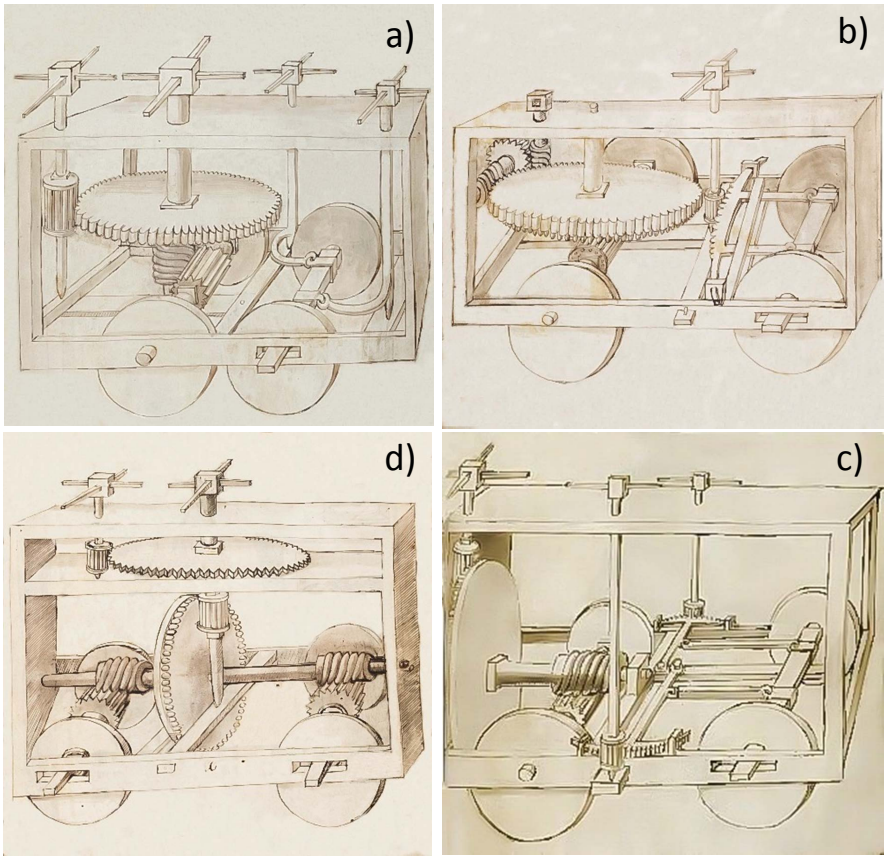

Figure 4. Designs of four-wheel vehicles set in motion by manually driven gears and with directional control. Francesco di Giorgio. *Opusculum de Architectura*, (a) folio 3r, (b) folio 29v, (c) folio 31r e (d) folio 4r (details). British Library Museum. London. UK.

direction. The different projects explore possible configurations of the mechanics of these systems, tracing in this the studies of Francesco di Giorgio on other types of machines, such as the hydraulic ones, the subject of numerous projects in the various codices.

The drawings in **Figure 5** show four other vehicle designs made by Francesco di Giorgio and featured in the *Opusculum de Architectura*. The projects differ from the previous ones because the wheels are toothed, and in two cases, some ploughs clearly show which use the Siena engineer had in mind. The pair of ploughs is positioned on the side below the load-bearing structure. They are not systems intended for theatrical use, like Leonardo's mechanical chariot, but practical applications. The vehicles are designed to move in muddy terrain and plough the ground, and to all intents and purposes, they can be considered the forerunners of modern tractors.

The ploughing machine in **Figure 5(b)** is characterized by a front driving wheel to which the drive shaft transfers the movement via a spool. The usual spool system at the rear of the machine allows steering by moving the wheels through a gear with a toothed circular section. In addition, the ploughs can be adjusted in height to be able to dig at different depths.

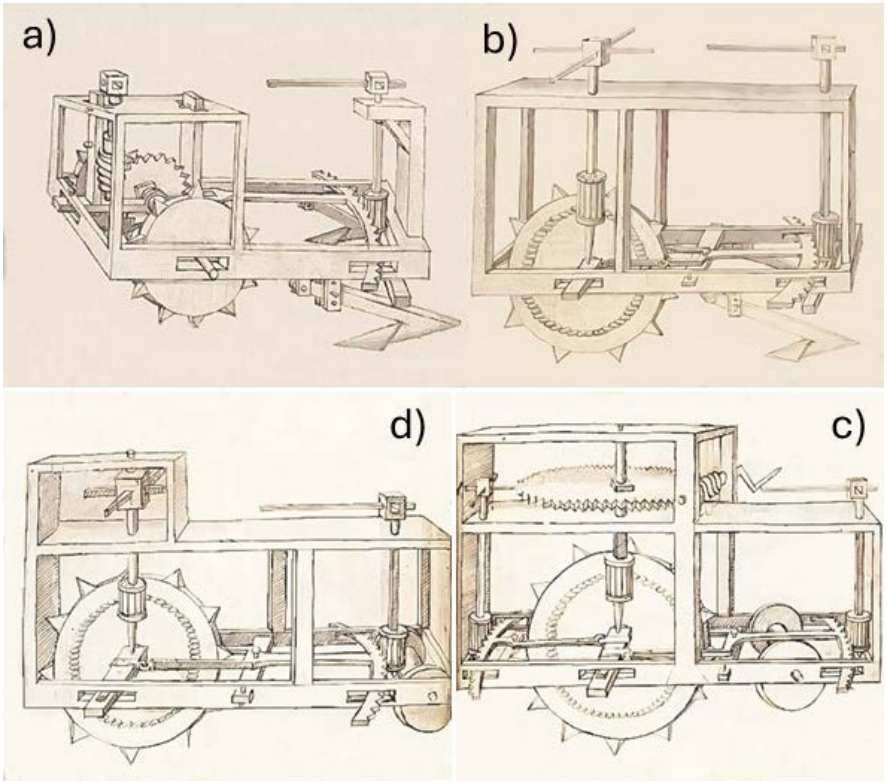

Figure 5. Gear wheel vehicle designs for moving in muddy terrain. Francesco di Giorgio. *Opusculum de Architectura*, (a) folio 22v, (b) folio 23r, (c) folio 24r e (d) folio 24r (details). British Library Museum. London. UK.

Another self-propelled machine for working the soil is found in folio 5r of the *Opusculum* and consists of two front driving wheels set in motion by a toothed wheel which, thanks to lateral pegs, makes one pair of hoes (**Figure 6**). The control of the direction of movement takes place through the pair of rear wheels moved with a drive shaft equipped with a spool in the lower part with which the wheels can be moved to the right or left.

The most fascinating drawing among those of Francesco di Giorgio's self-propelled vehicle designs is undoubtedly the one shown in folio 25v of the *Opusculum*, where the machine is drawn so that the observer could see it projected three-dimensionally on the background of the sheet (**Figure 7**) (Lamberini, 2001). This graphic representation allows for the appreciation, at first sight, of the mechanics of the system. The system is the most complex and mechanically evolved compared to the others.

There are four steering wheels each operated by an independent operator placed on the roof of the frame of the vehicle. In total, at least six people are required to manovrate the self-propelled vehicle, four for the drive wheels and two to change direction of the front and rear wheels.

An alternative study of internal mechanics is reported in folio 26v of the *Opusculum* (**Figure 8**). The two front drive wheels are independent and moved separately through two distinct drive shafts operated by different operators.

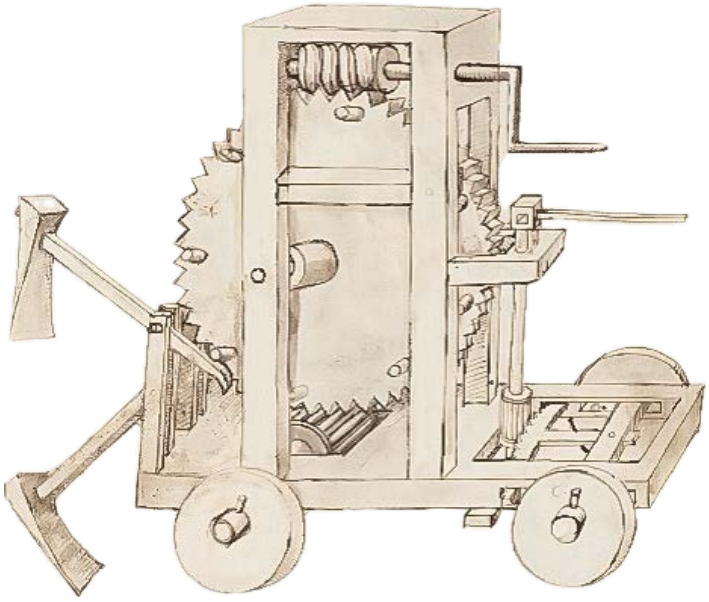

Figure 6. Project of a ploughing machine. Francesco di Giorgio. *Opusculum de Architectura*, folio 5r (detail). British Library Museum. London. UK.

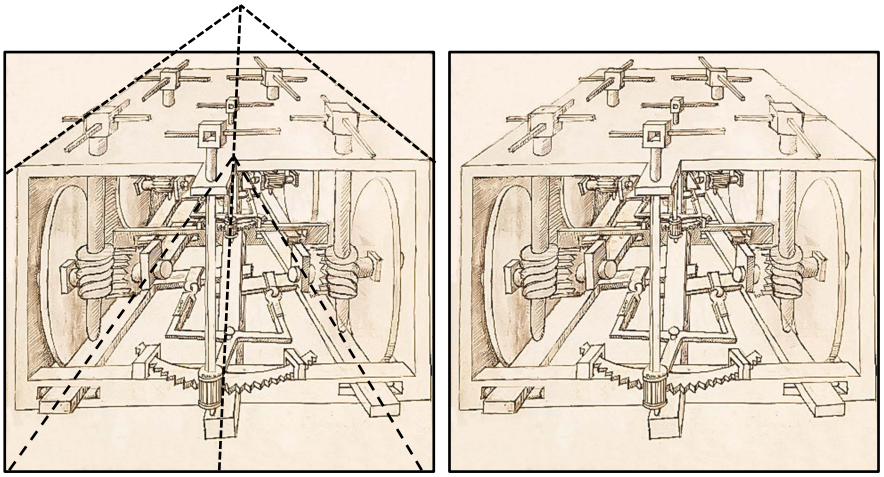

Figure 7. Vehicle project in 3D. Francesco di Giorgio. *Opusculum de Architectura*, folio 5r (detail). British Library Museum. London. UK.

Francesco di Giorgio considers two different mechanical solutions for this machine, one on the right in the drawing in which he uses a rack and pinion beam and the other on the left with a toothed sector beam.

5. The Projects in the Codex Ashburnham 361 and Codex Saluzziano 148

The *Opusculum de Architectura* contains the most extensive and complete collection of self-propelled vehicle projects from Francesco di Giorgio. The projects appear, however, also in the other manuscript copies of the *Trattato di Architettura* of Francesco di Giorgio, particularly in the *Codex Ashburnham* 361 and *Codex Saluzziano* 148, which correspond to the first version of the *Trattato*.

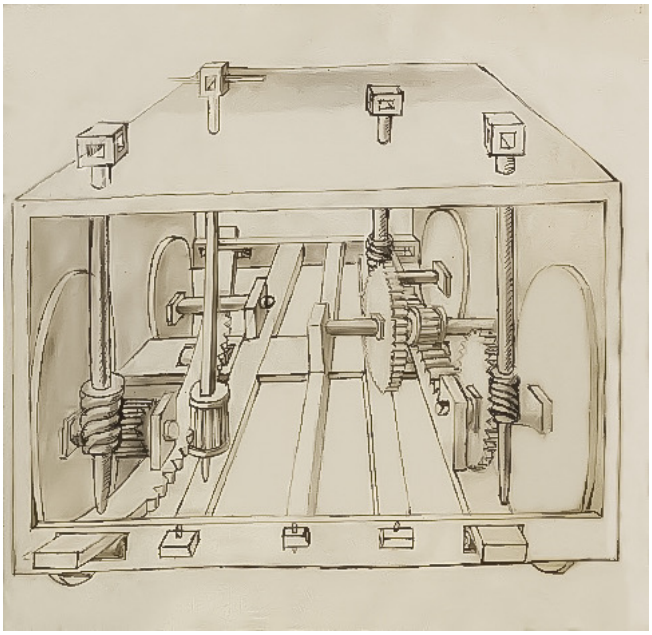

Figure 8. 3D drawing of a self-propelled vehicle. Francesco di Giorgio. *Opusculum de Architectura*, folio 26v (detail). British Library Museum. London. UK.

Unlike the *Opusculum de Architectura*, which is essentially a collection of drawings without any text, the projects of machines in these codices are accompanied by explanatory paragraphs describing their operation mode. The quality of the drawings is, in general, lower with respect to that of the *Opusculum* and the sketches in the two manuscripts differ for some details as such the accompanying text. In each of the two codices there are six self-propelled vehicle drawings, accompanied by a note explaining their operation and use. The description of the operation is quite detailed, and in some cases, even the measurements of the machine parts are given. From the looks of things, the vehicles appear huge, especially since several men must operate them from the roof. Considering the resulting size and weight, it is not easy to imagine that such machines could be moved easily, even by a large human crew.

All six designs appear as mechanical systems transmitting motion through a series of gears set in motion employing winches positioned on the roof. The systems are all shown inside a parallelepiped "box" open on two sides. The operators should stay on the machine's roof, some with the function of moving the wheels, others with that of driving it. On the other hand, the machine can only be driven from the roof since the front and rear sections are blind, as in most of the designs reported in the *Opusculum de Architectura*. **Figure 9** shows the first of six self-propelled cart designs in *Codex Saluzziano* 148 (**Figure 9(a)**) and *Codex Ashburnham* 361 (**Figure 9(b)**). The explanatory text in the two codices differs little. In the first description that appears of the self-propelled cart, Francesco di Giorgio clearly explains his intentions to make a cart that moves without animal traction: "*You can build a vehicle that moves without the aid of animals*

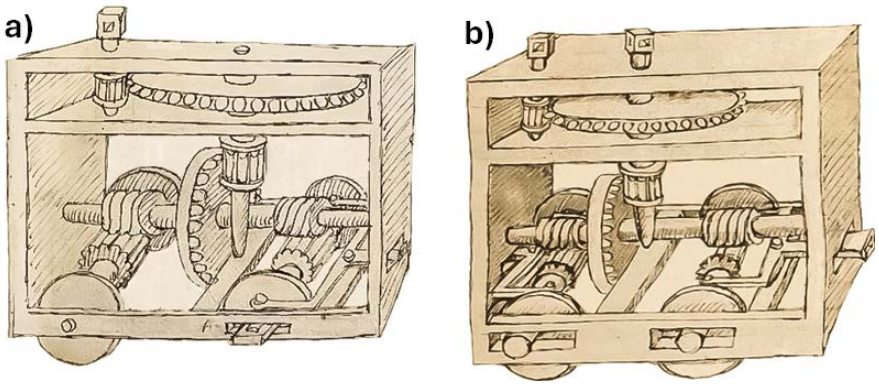

Figure 9. Francesco di Giorgio. (a) *Codex Saluzziano* 148, c. 52r (detail). (b) *Codex Ashburnham* 361, c. 46v (detail).

by using your ingenuity (*Quando alcuno carro per tirare senza bestie, ma con ingegno fare si può*) (*Codex Ashburnham* 361, c 46v)." Francesco di Giorgio's idea is precisely that of an automobile system, a vehicle that does not use animal power to move (Marchis, 1991). This important conceptual step is clearly expressed for the first time as an engineering project. The Sienese engineer does not attempt to solve the problem of the "engine"; the driving force will be the human one, and he focuses his attention on mechanics and systems to transmit motion and drive the cart. A vehicle moved by animal traction does not need a sophisticated system for driving and transmitting motion; the main problem is a suspension system allowing a more comfortable journey. Only an automobile needs a complex mechanical system to control the motion of individual parts and the direction of movement. This is the reason why the innovation introduced by Francesco di Giorgio should not be underestimated. It cannot be defined as an automobile in the modern sense because it lacks an autonomous motor capable of supplying the energy necessary for motion. However, the engineering of the system can be seen as an anticipation of what real cars will be in the future, at least in their basic mechanics.

The vehicle shown in **Figure 9** cannot run; it has four driving wheels, and in the first case, they are all steered, and in the second, only the front ones. Slots are opened in the chassis for steering movement, two or four depending on the number of steered wheels in the two versions. However, the direction of movement in the machine, as shown, cannot be controlled, making manoeuvring impossible. The movement of the drive gear is described in detail; a horizontal toothed wheel is positioned in the compartment below the surface and is set into rotation by an operator on the roof via a vertical sprocket. The sprocket consists of a cylindrical gear whose teeth or rollers engage that of a major wheel, which is then set in motion. The movement of the horizontal wheel is then transmitted via another sprocket to a vertical toothed wheel, which finally transmits it to the drive shaft and, through this, by endless worm screws to the wheel axle.

In the explanatory notes accompanying the text, Francesco di Giorgio makes explicit reference to the dimensions of the gear wheels, the horizontal one being

five feet (piei cinque) and the vertical one being four feet (piei quattro) in diameter. If the Florentine foot of 32.48 cm is taken as a reference, the gear wheels would then be 162.4 and 129.92 cm in diameter. The drawing in Figure 9(b) of the *Codex Ashburnam*, which seems to respect the scale of the various components better, makes it possible to estimate what the possible size of the chariot might have been: about 3 meters in length, 4 in height, and 3 in width, thus 3 × 4 × 3 meters. The size assessment is obviously approximate due in part to the uncertainty of the foot (piede) measurement used as a dimensional reference. However, it appears compatible with the measurements of a wagon operated by two people.

Subsequent designs (Figure 10) solve the problem of steering movement since it can be maneuvered from the roof using two vertical rods attached to the steering block (Figure 10(a) and Figure 10(b)) or by means of a vertical sprocket that rotates the curved, toothed axle that controls the movement of the wheels (Figure 10(c) and Figure 10(d)). The system has only one pair of steering wheels, the front ones, while the "motor" is driven by a vertical sprocket or worm gear at the rear of the machine. This solution solves the problem of the steering wheels. It makes it almost impossible for operators positioned on the roof to set the system in motion due to the very limited space to operate. In the

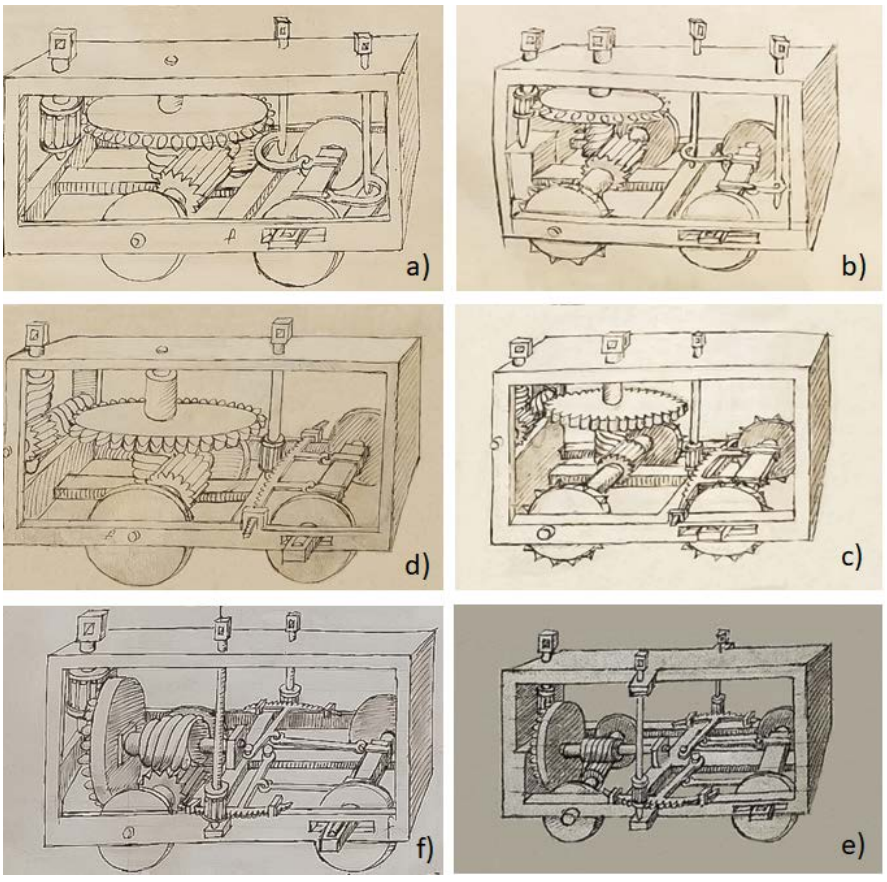

Figure 10. Carts (*Charri*). Francesco di Giorgio. (a), (d) and (f) *Codex Saluzziano* 148, c. 52r (details). (b), (c) and (d) *Codex Ashburnham* 361, c. 46v (details).

illustrations of *Codex Ashburnham* 361 (Figure 10(b) and Figure 10(c)) the wheels are toothed, the drive wheels in one case or all of them in the other.

A variant of the previous systems places the steering in a central position (Figure 10(e) and Figure 10(f)), but as in the previous cases, the position of the power take-offs on the roof makes it impractical for the operators to use the steering. This type of steering would also require coordinated movement by a pair of operators.

The plans in Figure 11 reproduce the same projects in the *Opusculum de Architectura* shown in Figure 7 and Figure 8, although they appear less graphically accurate. The "box" is now shown open at the front and rear instead of sideways, allowing the machine's mechanics to be observed in perspective. In the design shown in Figure 11(a) and Figure 11(b), Francesco di Giorgio finally arrives at a solution for positioning the steering wheel that allows the vehicle to be manoeuvred with only one person, placed at the front of the roof. The vehicle, however, as the Siena engineer describes, has four steered wheels and can be manoeuvred from the front as well as the rear, and sixteen or more men would be needed to set it in motion.

6. The Traces of Self-Propelled Vehicles in Taccola, Leonardo da Vinci and Antonio da Sangallo the Younger

The exploration of the world of machines and mechanical engineering begun by

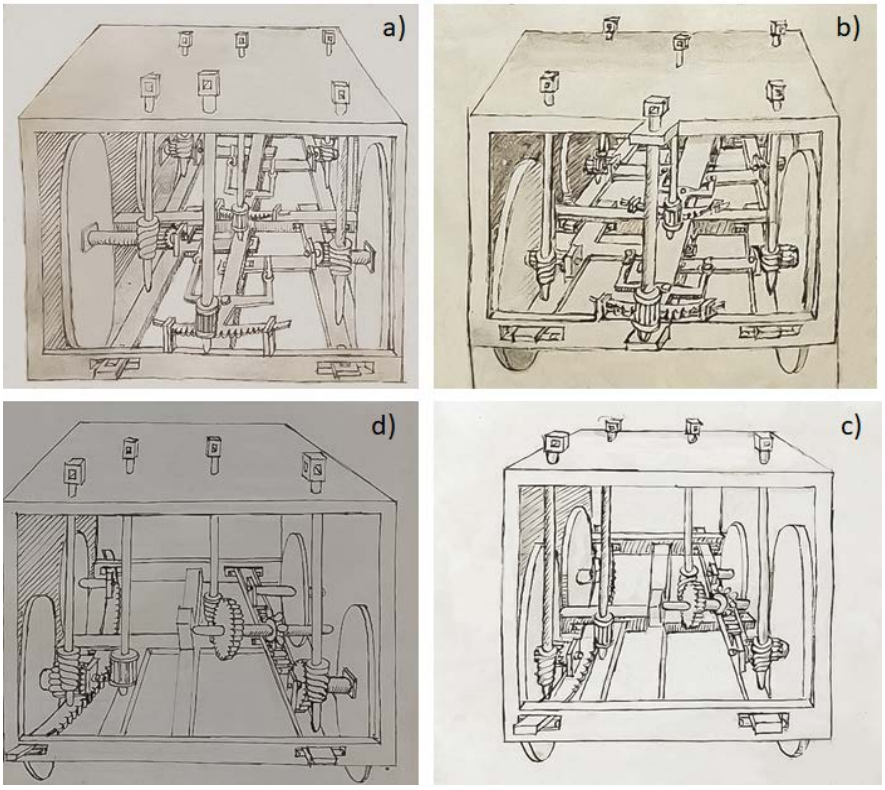

Figure 11. Carts (*Charri*). Francesco di Giorgio. (a) and (d) *Codex Saluzziano* 148, c. 52r (details). (c) and (d) Codex Ashburnham 361, c. 47r, c. 46v, (details).

Francesco di Giorgio has two probable sources of inspiration. One source was the machines in use in Italy during the Renaissance, which had a very high level of technical development resulting from a long and continuous process of innovation (Ceccarelli, 2008). The treatises of Taccola are other sources from which Francesco di Giorgio drew extensively for the compilation of his *Codicetto Vaticano*. It is important to ask whether Taccola may have also inspired him in the case of his plans for the mechanics of self-propelled chariots. In his treatises, we do not find traces of designs as well described and developed as those we have just reported; there is, however, a small, unnoticed drawing that represents a similar design to that of his younger fellow citizen. The drawing is in the engineering treatise, *De Ingeneis*, and shows a cart moved by a central cylinder that transmits motion to gear wheels (**Figure 12**). The drawing is poorly defined in detail but can be compared to those in **Figure 1** from the *Codicetto Vaticano*, which, as we have pointed out, contain, in good part, designs derived from Taccola. Therefore, Taccola is likely the source of the idea that later inspired Francesco di Giorgio to develop his systematic study of the mechanics of self-propelled vehicles.

Another interesting question is whether Francesco di Giorgio's vehicle designs, in turn, spurred other Renaissance engineers. Although Francesco di Giorgio's treatises were never printed, they had a great fortune because of the good circulation of the various manuscript copies. Leonardo da Vinci had come into possession, as we have seen, of a copy of the *Treatise on Architecture*, that of *Codex Ashburnham* 361, which he had personally annotated. The influence exerted by Francesco di Giorgio on Leonardo was therefore important, and many traces of the Sienese engineer's ideas can be found in the pages of Leonardo's codices (Innocenzi, 2022).

Leonardo da Vinci designed many automata, including the mechanical lion, the "robot" soldier, and the theatrical cart, but no projects similar to that of Francesco di Giorgio appear in the pages of the codices that remain. Leonardo's project of a small theatrical cart has a considerable degree of mechanical complexity and employs a system of leaf springs as a form of an engine to travel a short distance of a few meters.

These designs, however, can be categorized within automata and an actual idea of self-propelled vehicles for transporting people Leonardo would not have developed it. There is, however, a small sketch in Folio 868r of *Codex Atlanticus* that shows an exciting design of a four-wheeled chariot that, from what can be deduced, should be moved by two cranks operated at the front (**Figure 13**). The two cranks should transmit motion directly to the two front wheels. It cannot be concluded that Francesco di Giorgio inspired this small drawing, but it is probably the only trace of a self-propelled vehicle by Leonardo da Vinci.

Another original drawing can be found in Antonio da Sangallo the Younger (1484-1546) (Architectural History Foundation, 1995), who evidently echoes, to some extent, the basic concept used by Francesco di Giorgio for the transmission

of motion in a self-propelled vehicle (Figure 14). The cart is again shown as a giant open box on the back of which are placed two winches that set in rotation a worm screw that transmits motion to toothed wheels placed on the axle that turns the wheels. According to Sangallo: "…*this is the mechanics of a vehicle that is set in motion by standing on it like those of ancient wooden towers and tortoises and similar things for which it was necessary to stand in the machine for that made them go*…" Sangallo was referring to war machines, such as testudos that were set in motion by men who were protected by wooden shields, of which, however, there is no trace in his plan.

7. Copies of Francesco di Giorgio's Self-Propelled Vehicles in Later Manuscripts

The success of Francesco di Giorgio engineering treatises is evidenced by the many copies made of his works, which were plundered and reproduced with minimal changes, by various authors. There are many examples, including copies of self-propelled machines. Unlike the previous examples, where one can identify mutual influences and originality in the design of the machines, in the case of Francesco di Giorgio epigones, these are in most cases mere copies.

An example can be found in Giuliano da Sangallo's Codex Barberiniano (Manuscript Barb. Lat. 4424, n.d.). The treatise houses two meticulously copied drawings by Francesco di Giorgio. Figure 15(a) is an almost exact replica of the one in Figure 10(b), while Figure 15(b) is a remarkably faithful reproduction of the one in Figure 5(a), with a minor variation in the positioning of the crank that drives the wheel's movement, now horizontal instead of vertical.

Another significant example can be found in the pages of the treatise "Raccolta di varie macchine e disegni di vasi antichi (Collection of various machines

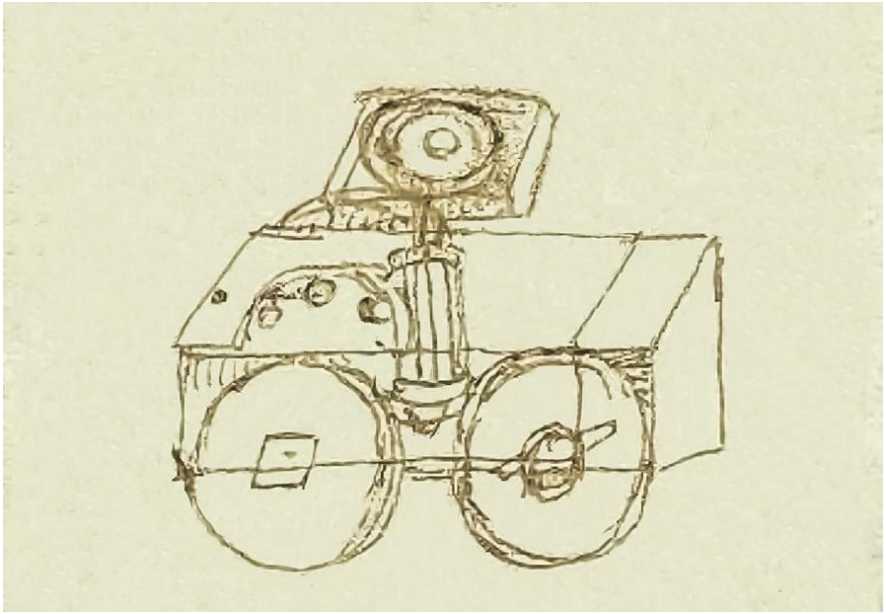

Figure 12. Design of self-propelled vehicle. Taccola. Folio 38v (detail). *De Ingeneis*.

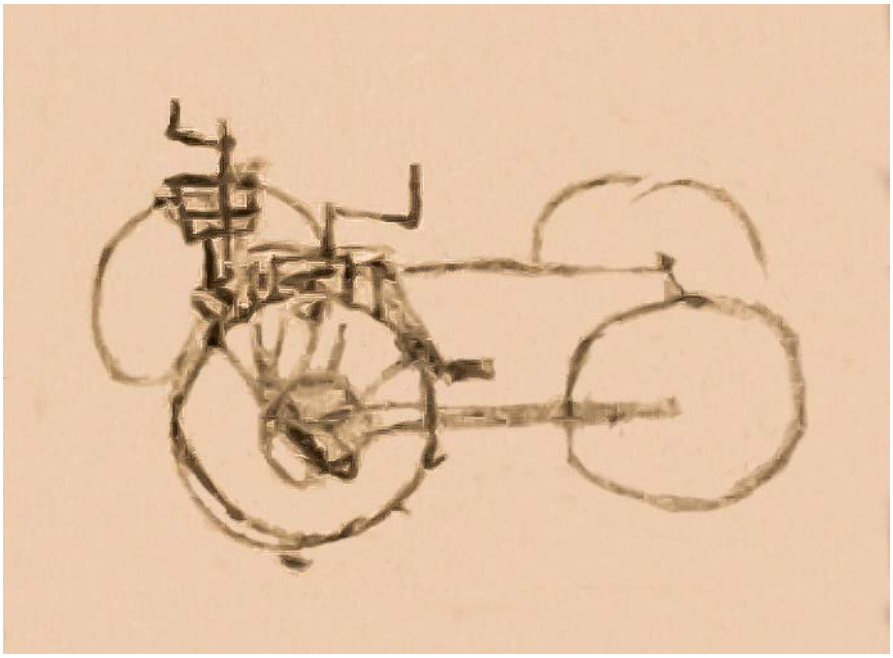

Figure 13. Sketch of a self-propelled cart from Leonardo da Vinci. Folio 868r, *Codex Atlanticus*. Ca. 1486. Veneranda Biblioteca Ambrosiana. Milan.

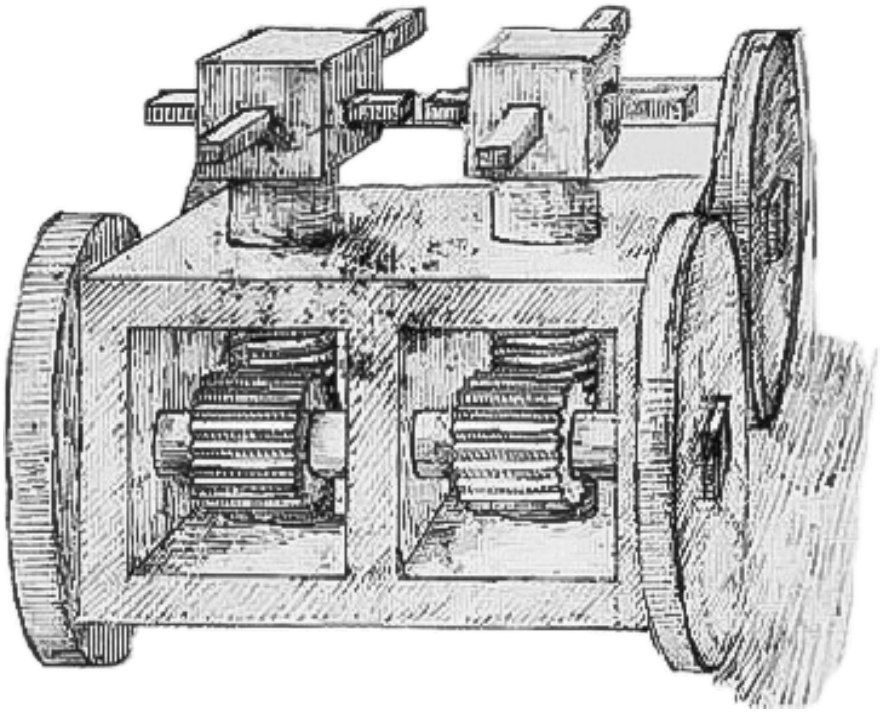

Figure 14. Self-propelled wagon driven by winches. Antonio da Sangallo the Younger. Disegni di architettura (Architecture drawings), 1450Ar (ca 1526) (detail). Gabinetto dei Disegni e Stampe, Uffizi, Florence.

and drawings of ancient vessels)" by Cosimo Bartoli (Bartoli, n.d.) (1503-1572) (**Figure 16**). The copies are accurate, and no significant elaborations are added.

Further copies of the self-propelled vehicle can be found, for instance, in the

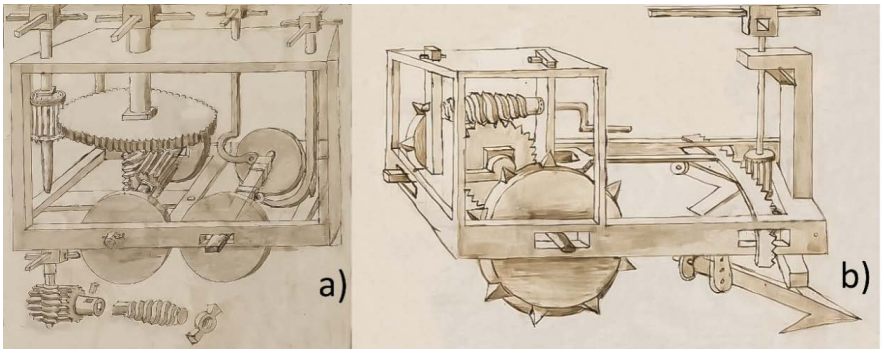

Figure 15. Copies of self-propelled vehicles by Francesco di Giorgio executed by Giuliano da Sangallo. Folio 60r (a) and Folio 62r (b), (details). Manuscript Barb. Lat. 4424 (n.d.). Biblioteca Apostolica Vaticana. Vaticane State.

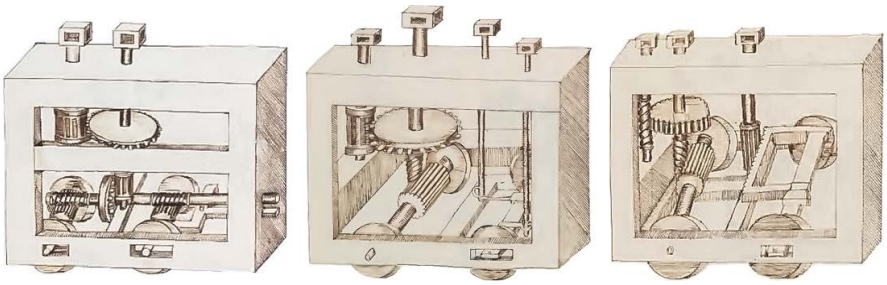

Figure 16. Copies of Francesco di Giorgio vehicles by Cosimo Bartoli. Manuscript E.B.16.5. Folios [3]96r and 96v (details). Biblioteca Nazionale di Firenze, Italy.

Palatine Manuscript 1077 (Manuscript palatino 1077, n.d.)[4], in the *Organa Mechanica* by Anonymous (Anonymous, XVI century)[5], just to name a few among the numerous treatises that house part or all of Francesco di Giorgio's machines. This abundance of examples underscores the historical success of the idea of self-propelled vehicles.

8. Conclusion

Francesco di Giorgio's self-propelled vehicles remain as a testimony of a brilliant intuition far ahead of its time. The possibility that a vehicle could move autonomously was a fascinating but impractical idea due to the lack of an energy source capable of setting the machine in motion. However, the studies of Francesco di Giorgio are extremely detailed in the design of the mechanical parts that transmit the motion and turn the vehicle. There is no evidence that these projects have ever been made or tested even on a small scale; they are theoretical models used to study different mechanical solutions assuming that the source of the movement is the human force. For this reason, the dimensions of these self-

[3]The folios: 13v, 15v, 25r, 27v, 32r, 41r, and 44v contain the notes and drawings by Leonardo da Vinci.

[4]Manuscript Palatino 1077 (n.d.). Bernardo Puccini and Anonimo Palatino. Biblioteca Nazionale di Firenze, Italy.

[5]Organa Mechanica. Cod. Lat., cl VIII, 87 [=3048]. XVI century. Biblioteca Marciana diVenezia. Italy.

propelled vehicles are so large and have this particular structure with a flat roof where many operators could simultaneously guide and move the mobile structure thanks to a system of cranks. Francesco di Giorgio's intuition goes beyond using these self-propelled vehicles as a means of motion and their dimension and shape have suggested that the vehicles were thought of as parade machines. Francesco di Giorgio, however, also designed a series of self-propelled vehicles for more practical use, such as the machines for hoeing or ploughing the soil. It is an extraordinary insight into the future evolution of self-propelled machines, not only means for transporting people but also for carrying out specific jobs.

The engine is missing in Francesco di Giorgio's "automobile", but his extraordinary intuitions remain, such as using two or four steering wheels, rear or front-wheel drive, toothed wheels to grip in muddy terrain and the use of machines as supporting tools for manual work. Francesco di Giorgio was one of the first to understand that a self-propelled wagon needs a specific mechanics, very different from that of animal-drawn wagons. Francesco di Giorgio's proto-cars would have to wait a few more centuries to be able to move on their own, but the first seed for future developments had already been planted.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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