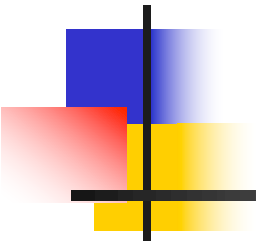


Leonardo da Vinci: Art, Kinematics and the Creation of Machines :



Francis Moon
Cornell University
RAND Corp 2015



Outline of Lecture

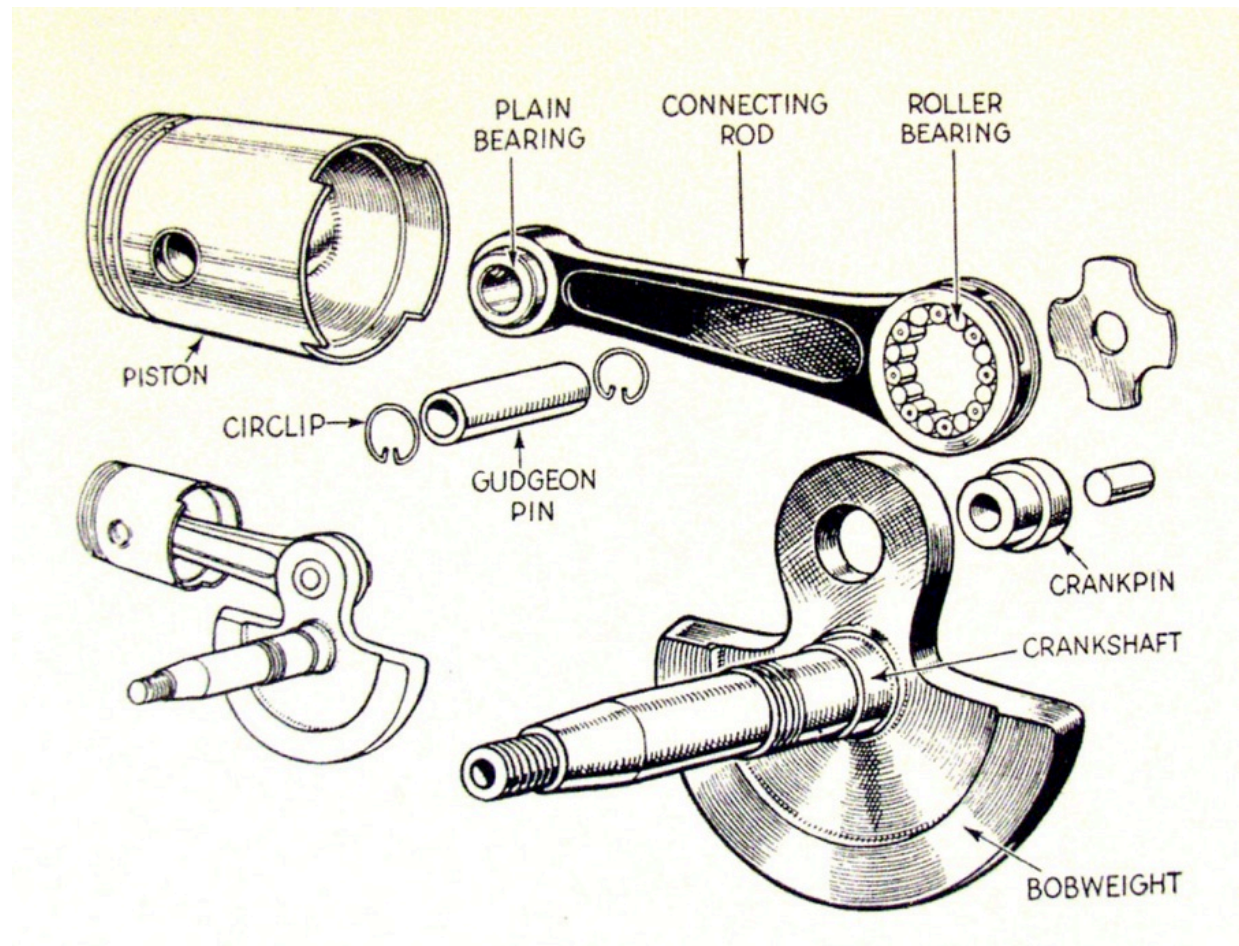
- How do Humans Create New Machines
- What Role did Leonardo play in the design of machines?
- How did ideas of machine design evolve into the industrial age?



Billions of Machines Each with 1000's of Components

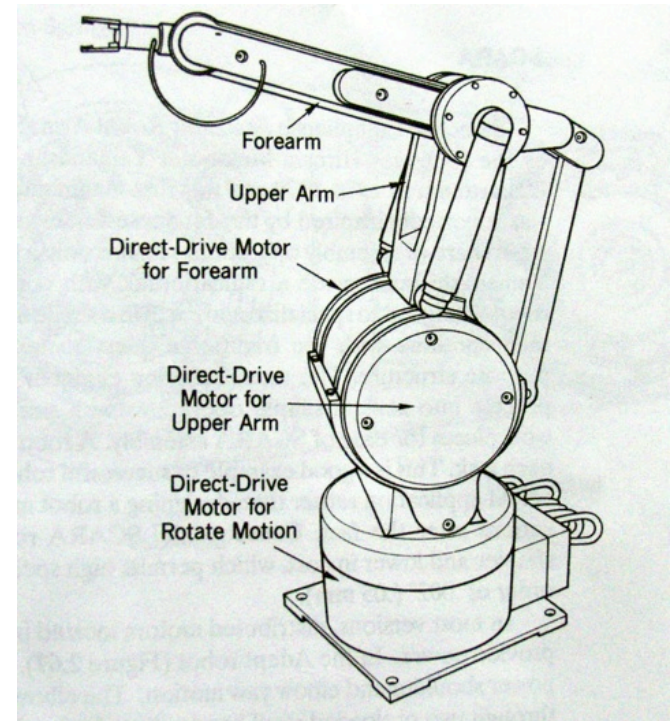
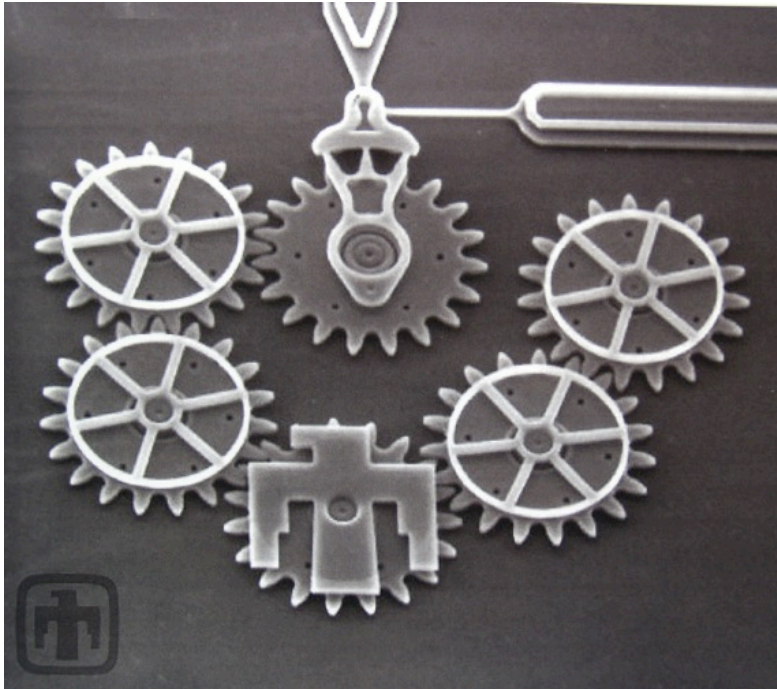
The heart of a machine is its topology, geometry and constraints between parts

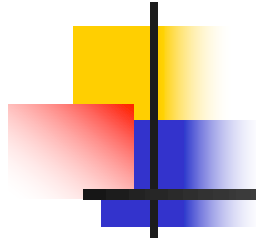
The modern automobile is estimated to contain 10,000 parts.





Machines come in a wide range of scales:





Elements of a Theory of Machines

Topology and Geometry

Kinematics

Dynamics

Tribology

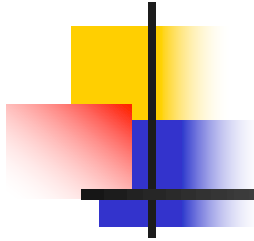
Thermodynamics

Control Theory

Mechatronics

Optimization Theory

Aesthetics



Leonardo: Artist or Engineer?

Dozen paintings

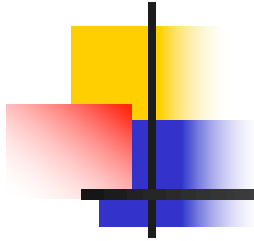
vs

1000+ Drawings of machines
and mechanisms

[Codex Madrid]



1452 - 1519



Leonardo da Vinci {Born 1452, Died 1519}

Born out of Wedlock

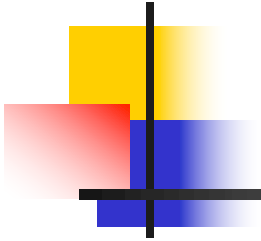
Apprenticed to Andrea del Verrocchio [1435-1488]

Member of the Guild of St Luke (painters) in Florence

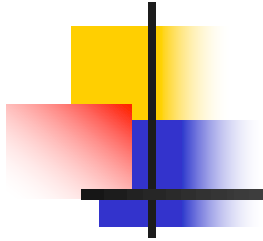
Left for Milan to work for Ludivico Sforza [1452-1508]

Worked for il Moro for 18 years

Met Francesco di Giorgio in 1490 in Pavia



Leonardo worked as
artist
architect
civil engineer
mechanical engineer
scientist
anatomy
mathematics

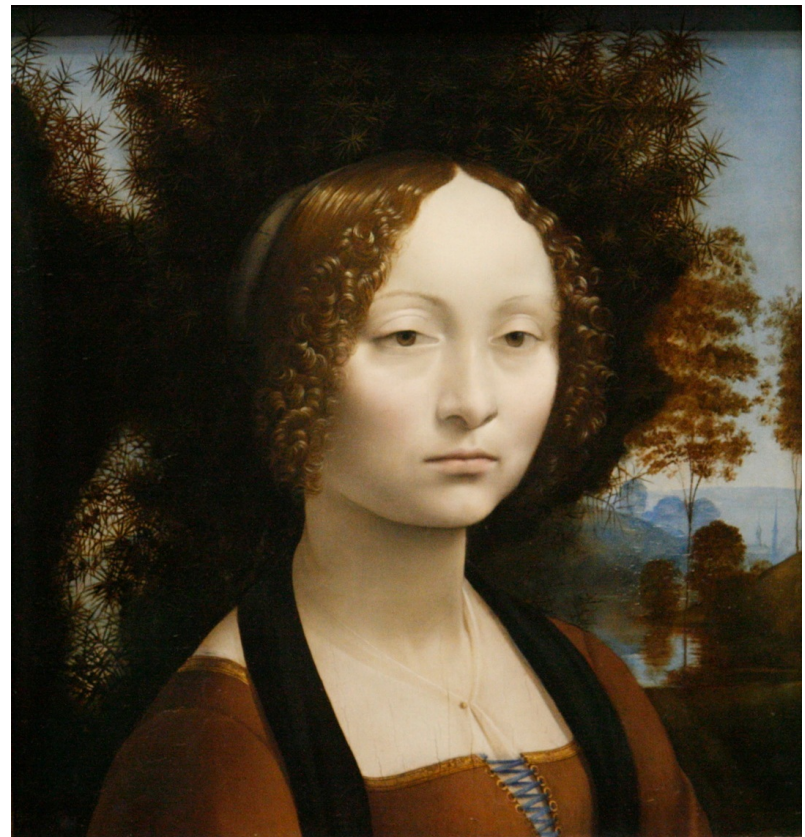


Genevre de Benci

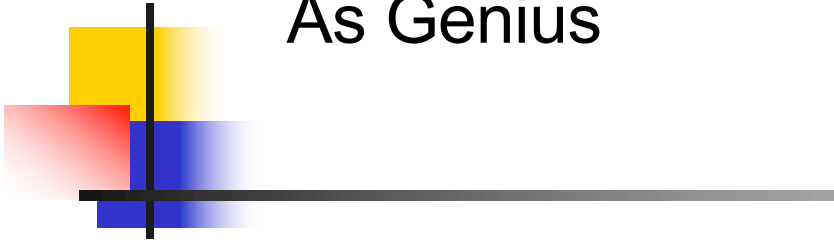
Portrait in National
Gallery, Wash DC

Completed c. 1474

Last Supper c. 1497
Mona Lisa c.1503



Popular View of Leonardo As Genius

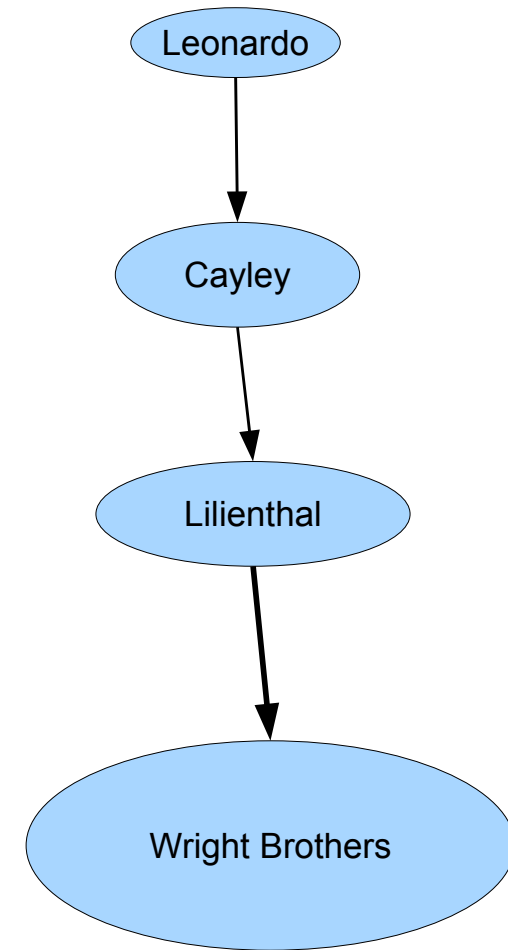


Theories of Human
Invention:

Genius Theory

Evolution

Social Network Model

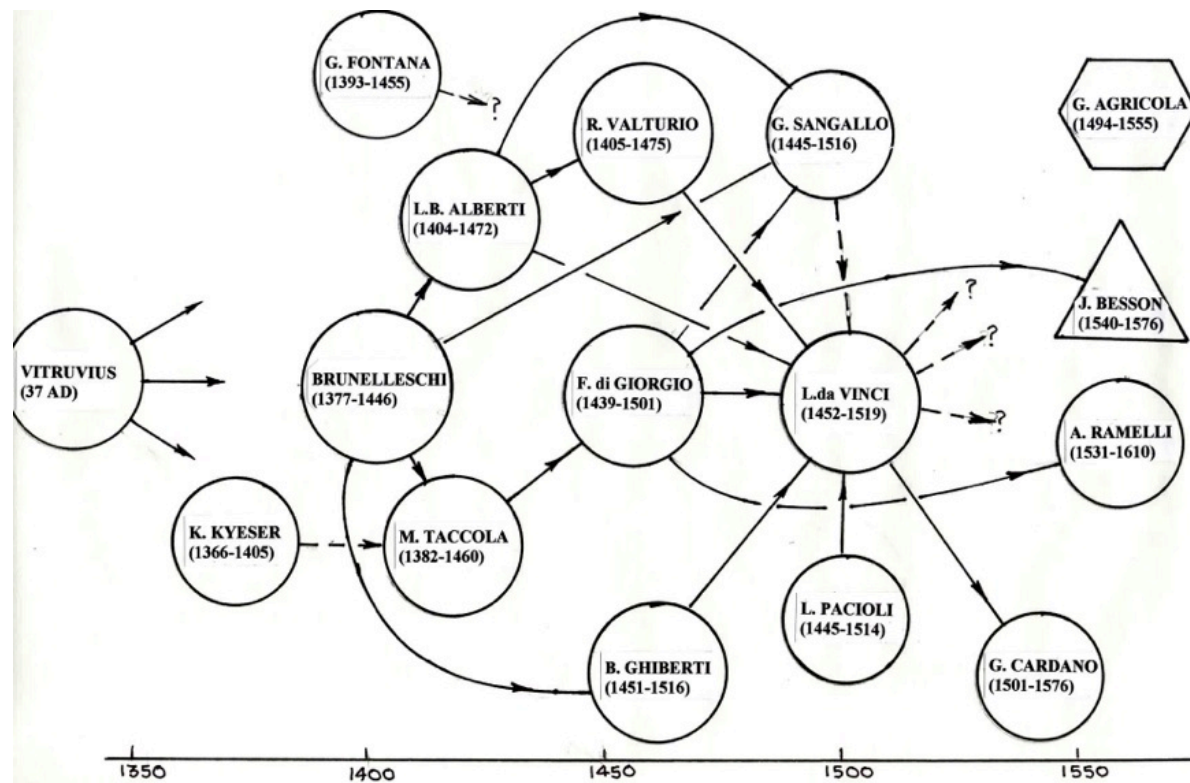


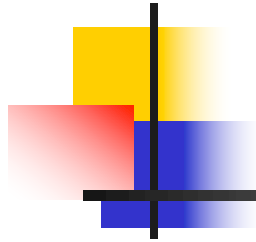
**The Genius Theory of Invention
of the Airplane**

Evolution of Machines

Social Network of Leonardo da Vinci

Every 'new' machine has evolved from an earlier machine.
e.g. Machine evolution in the Renaissance:





Leonardo's Drawings of Machines

Principal Sources:

Codex Atlanticus: Milan, Italy

Codex Madrid: Madrid, Spain

Manuscripts B, G, H: Institute de France, Paris



Classification of Leonardo's Machines

Manufacturing Machines: textile machines

Military Machines: Trebuchet, Catapults, Cross Bow

Construction Machines: Cranes, Pumps, Pulley Systems

Transportation: Flying Machines, Boat Paddle Wheels

Clock Mechanisms

Elementi Macchinali: Machine Elements



Leonardo's Machine Elements or Elementi Macchinali in Codex Madrid

Screws

Rivets

Bearings

Couplings

Flywheels

Cams

Gears

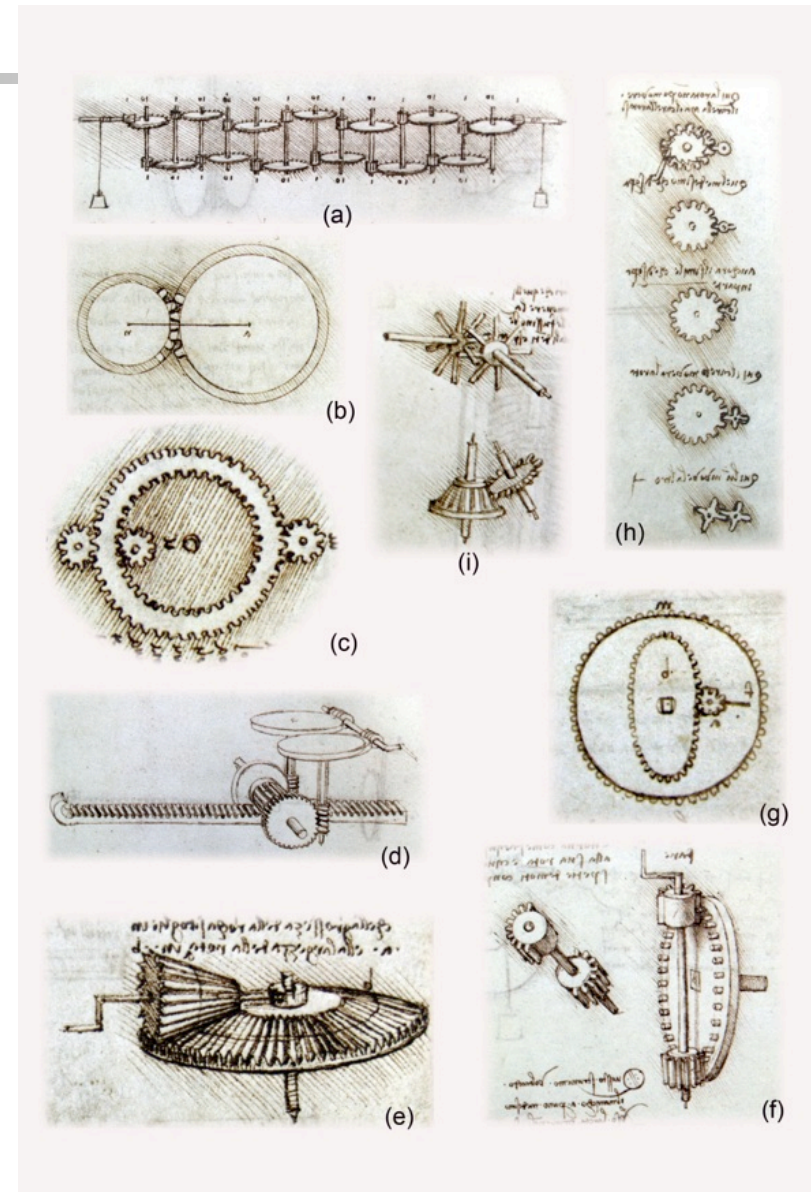
Belt drives

Valves

Renaissance Theory of Machines: Leonardo da Vinci's Kinematic Mechanisms

LdV Deconstructed complex machines into a set of basic machine elements
e.g. Bearings, pulleys, gears, etc

Samples of gear designs of
Leonardo from
the *Codex
Madrid*, c. 1490





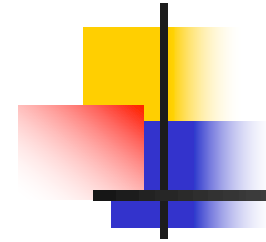
Past Theories of Machines

Greek Theory of Machines

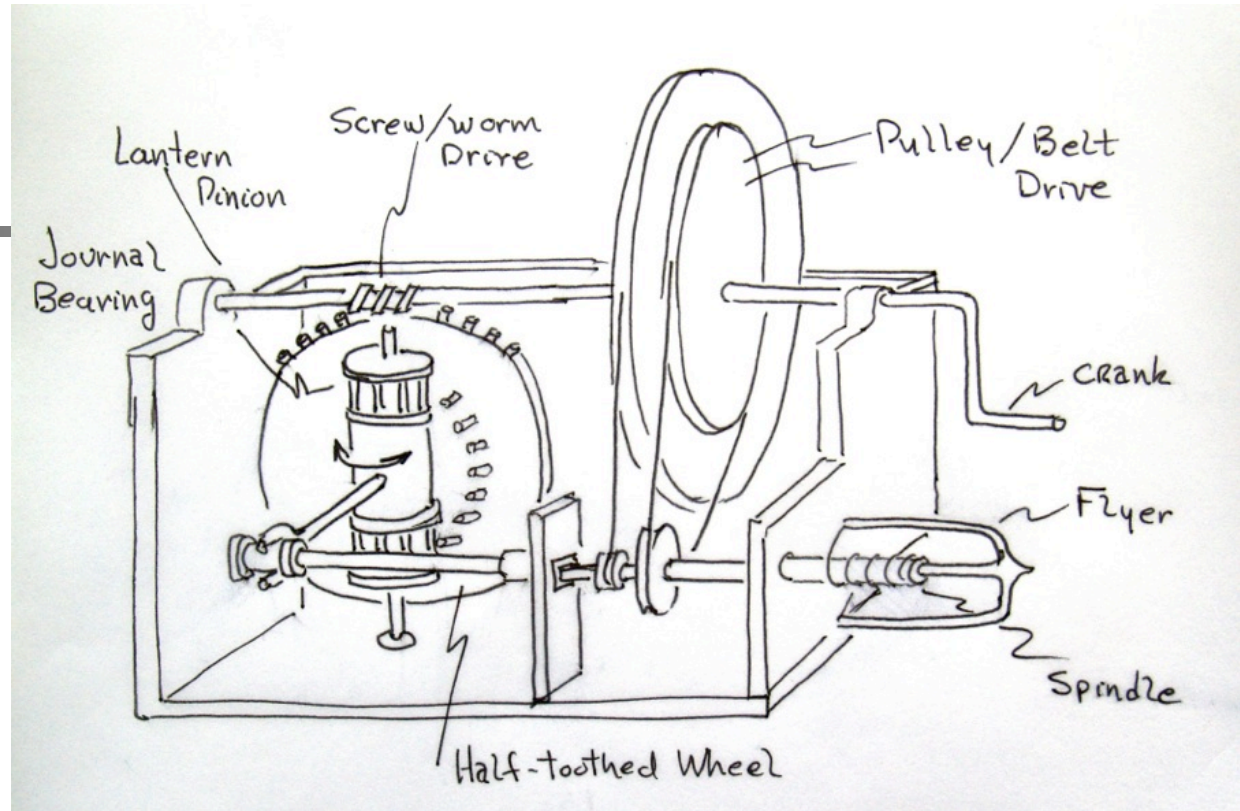
Aristotle Peripatetic School: Simple Machines

Map complex machines onto a set of simple geometric constructs:

1. Lever
2. Pulley
3. Screw
4. Inclined Plane
5. Wedge
6. Wheel



Leonardo as an Engineer-Artist



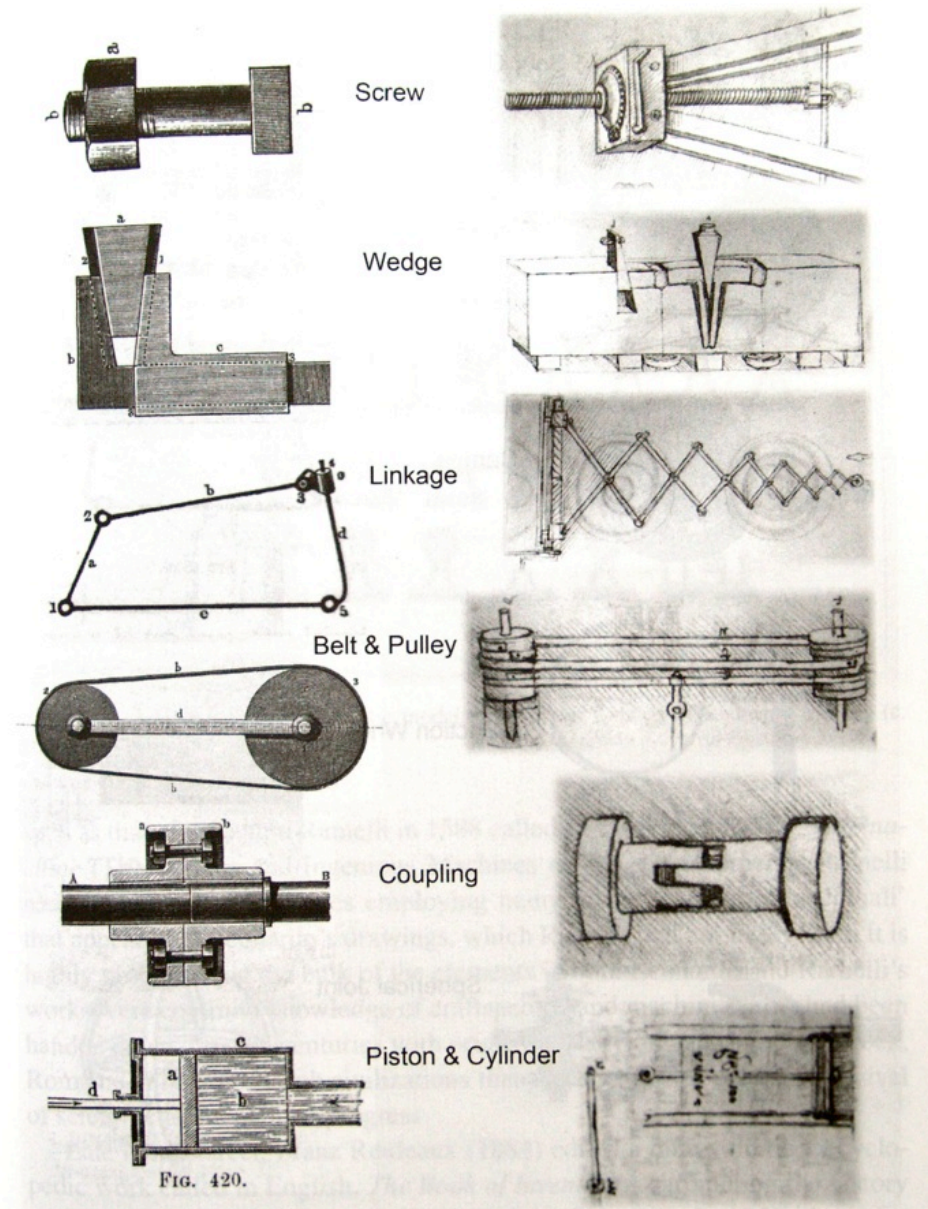
Deconstruction of [Leonardo da Vinci](#)
Textile Spindle Winding Machine into basic
Kinematic Mechanisms

[Codex Madrid]

Comparison of Machine Elements and Mechanisms:

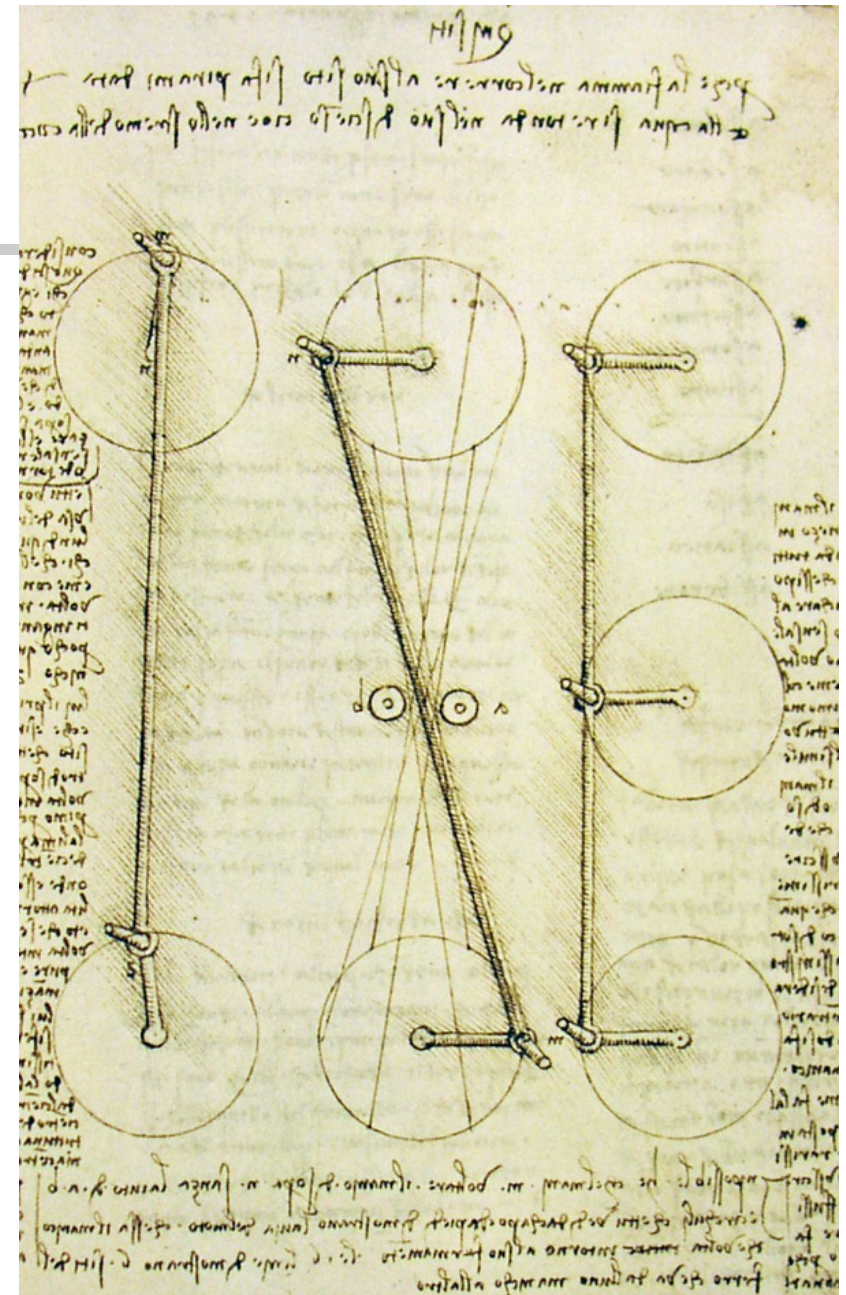
Leonardo da Vinci (Right)
[1490]

Franz Reuleaux (Left)
[1875]

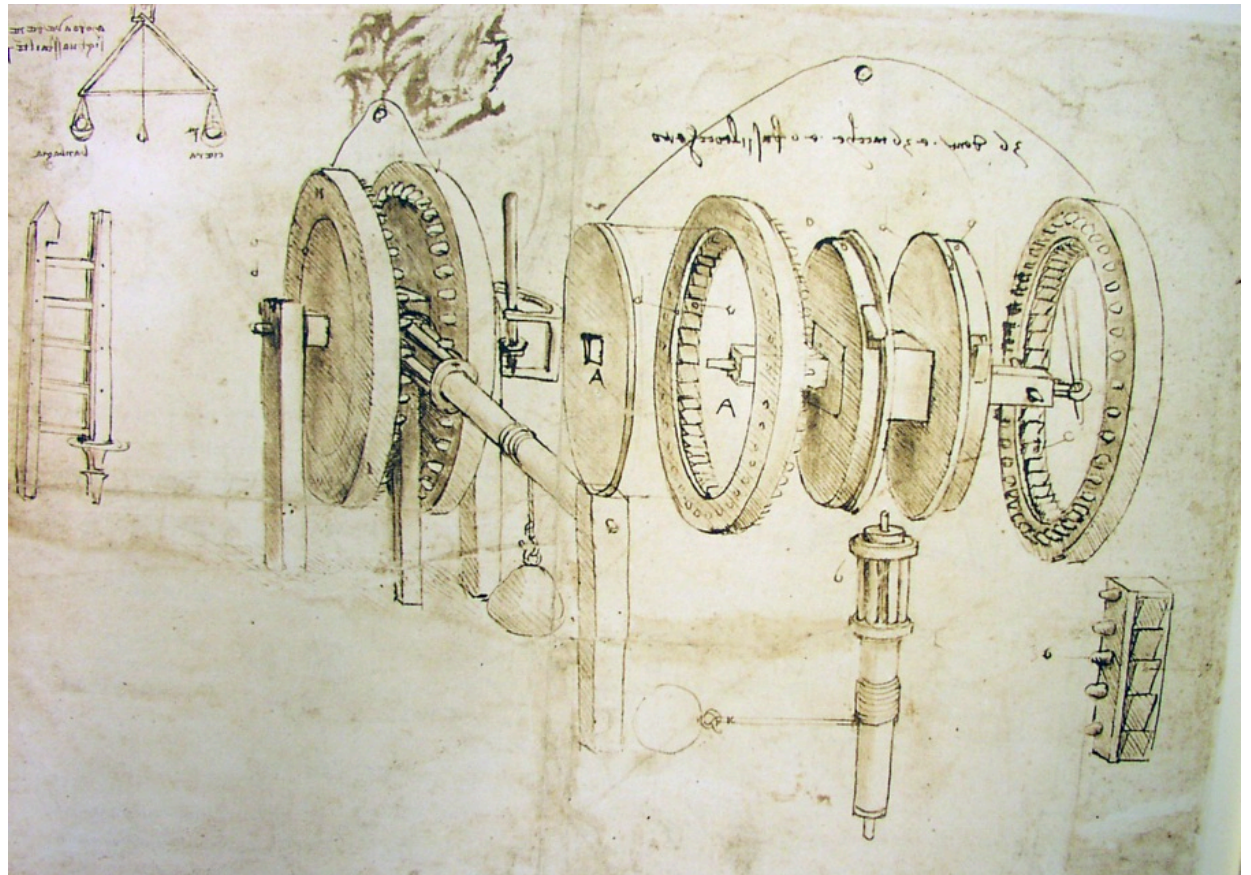


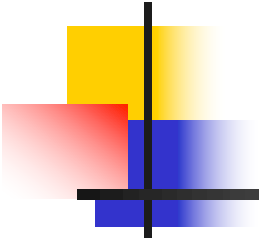
Four Link Mechanism

Codex Madrid

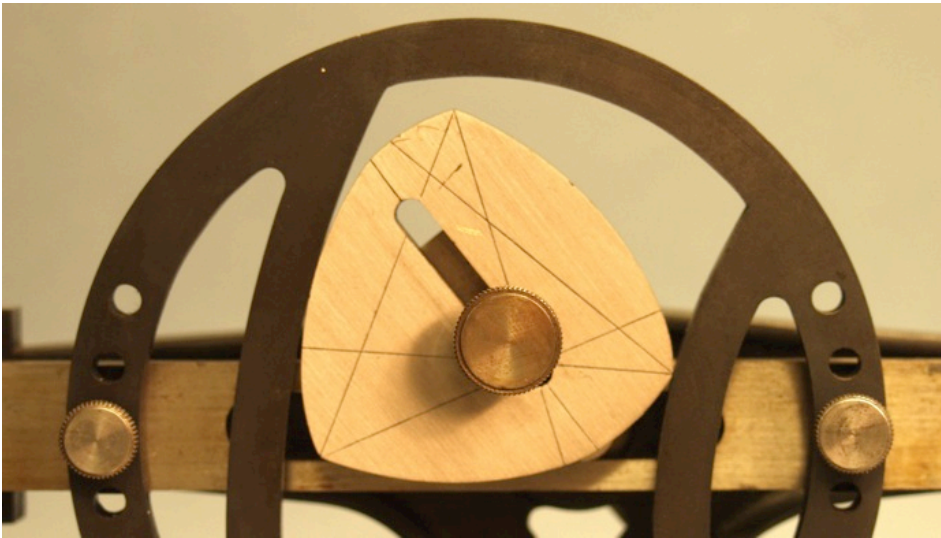


Leonardo was one of the first to use the exploded view of machine components

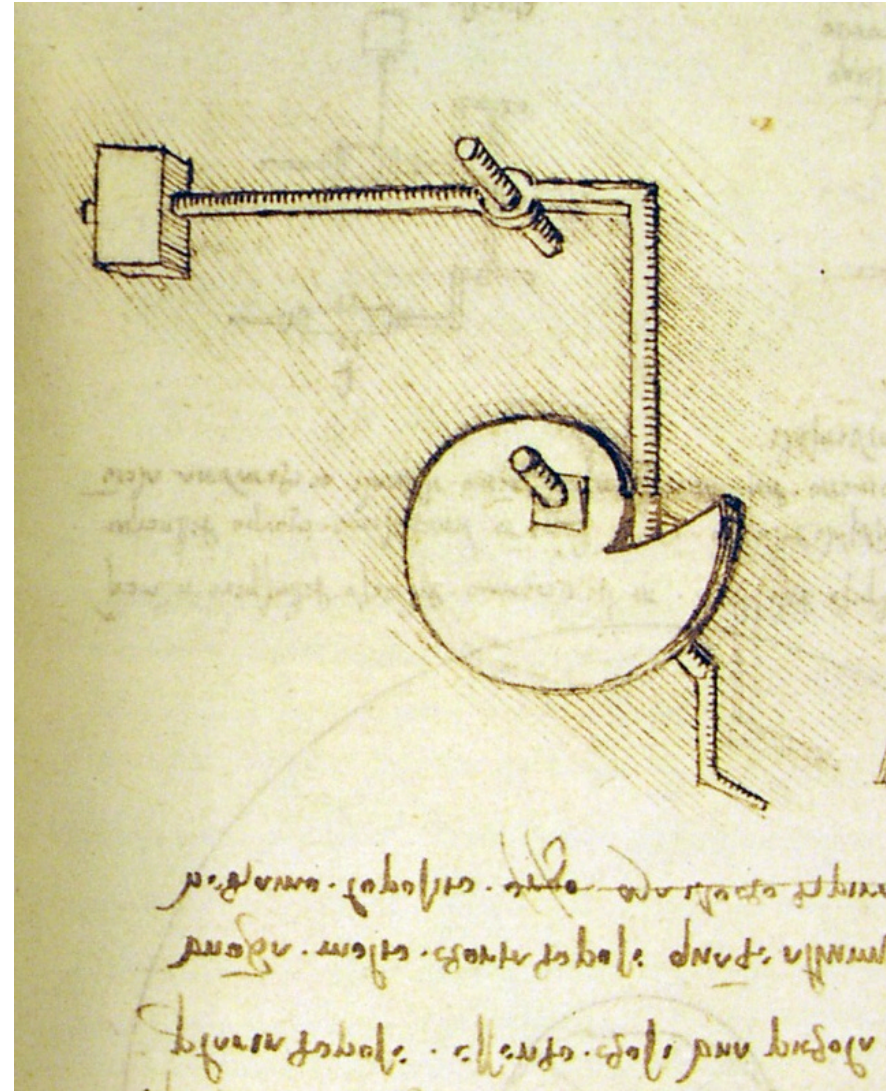




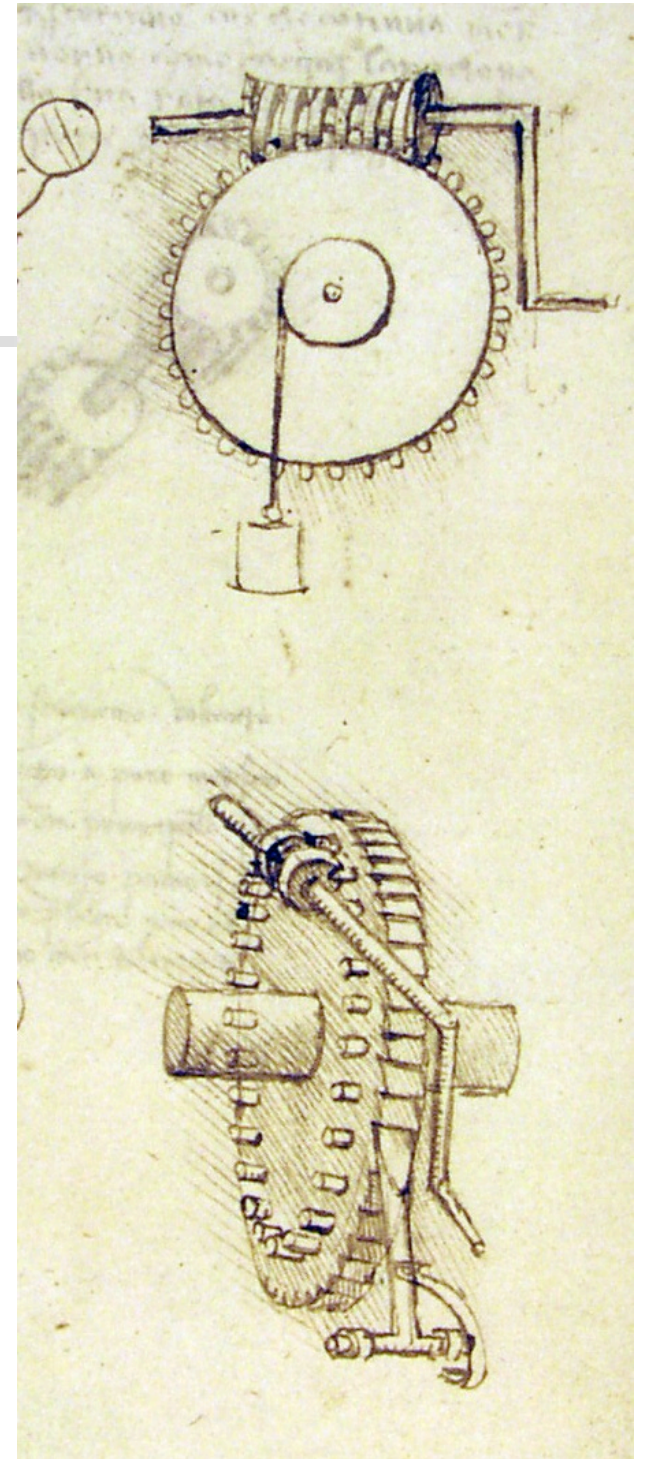
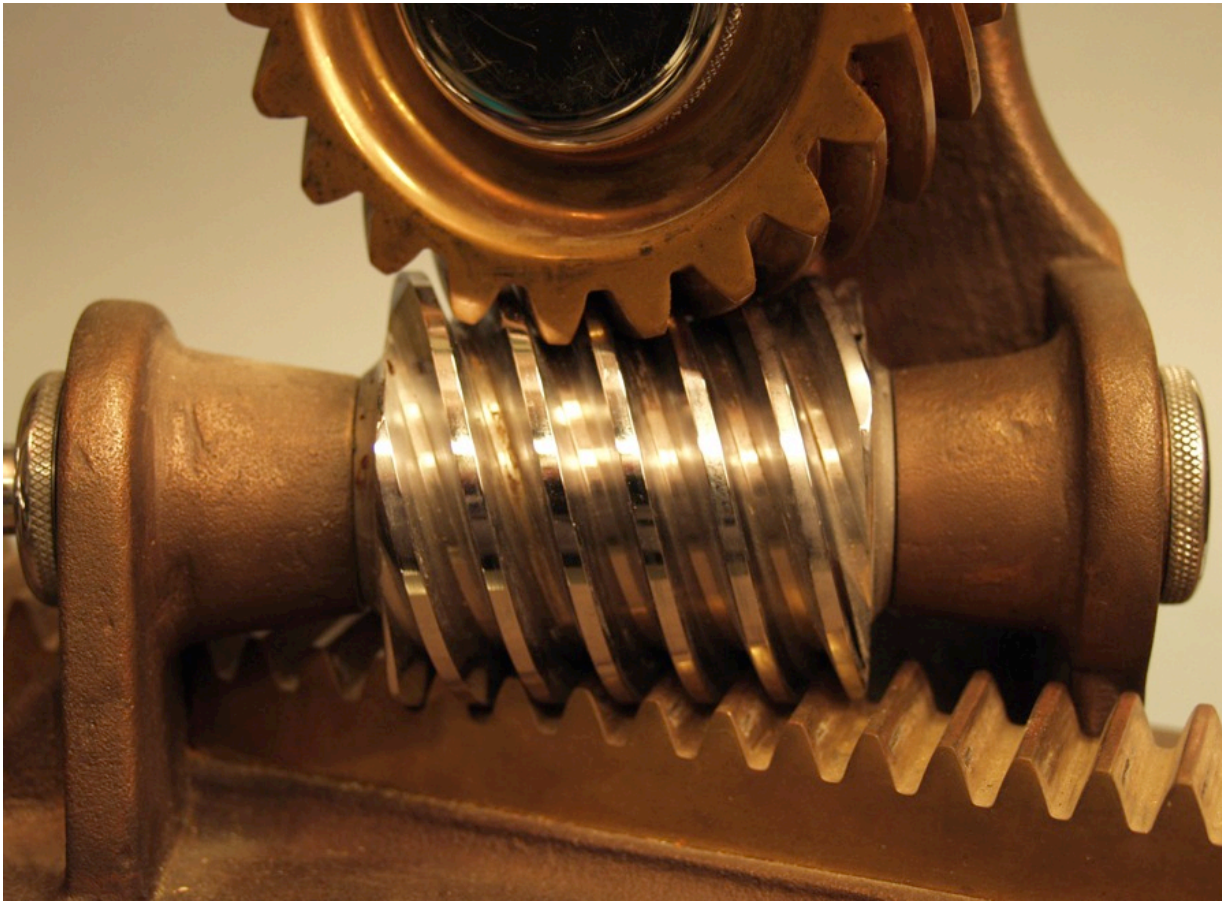
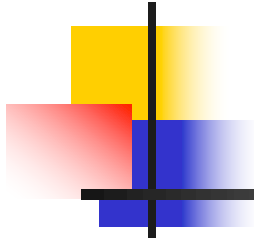
Cam Mechanisms of Franz Reuleaux (Rx) and Leonardo da Vinci (LdV) {c. 1870, 1470}



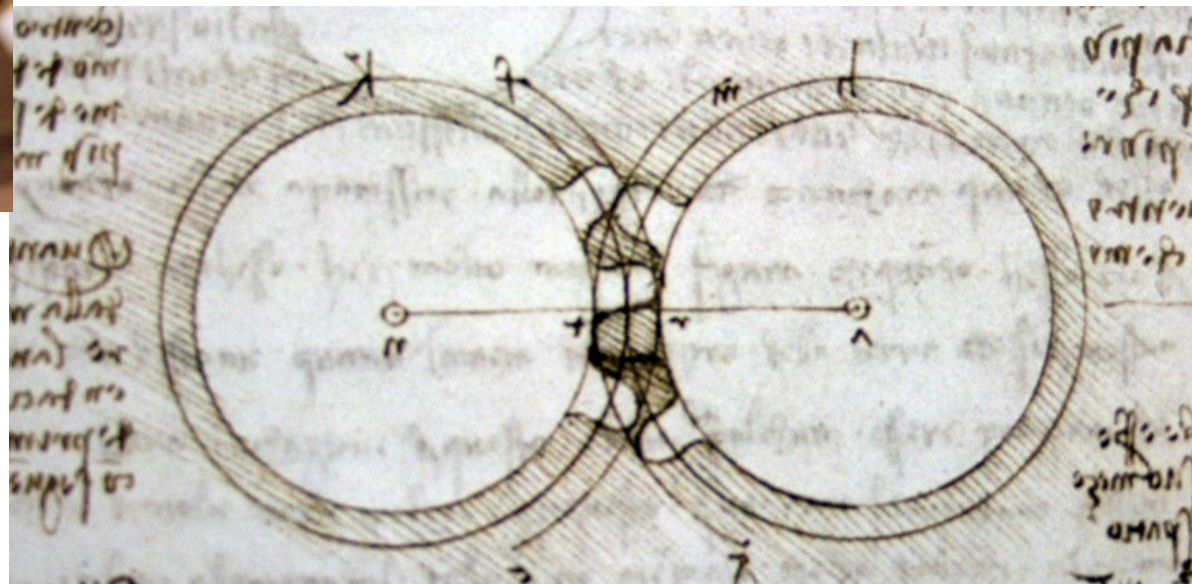
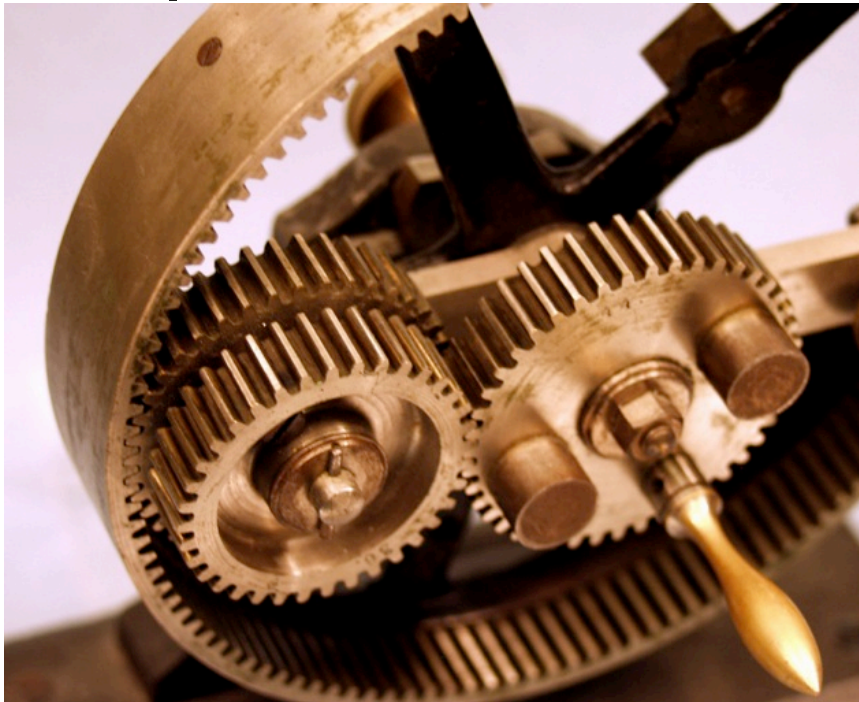
Rx mechanism in the
Cornell Collection of
Kinematic Mechanisms



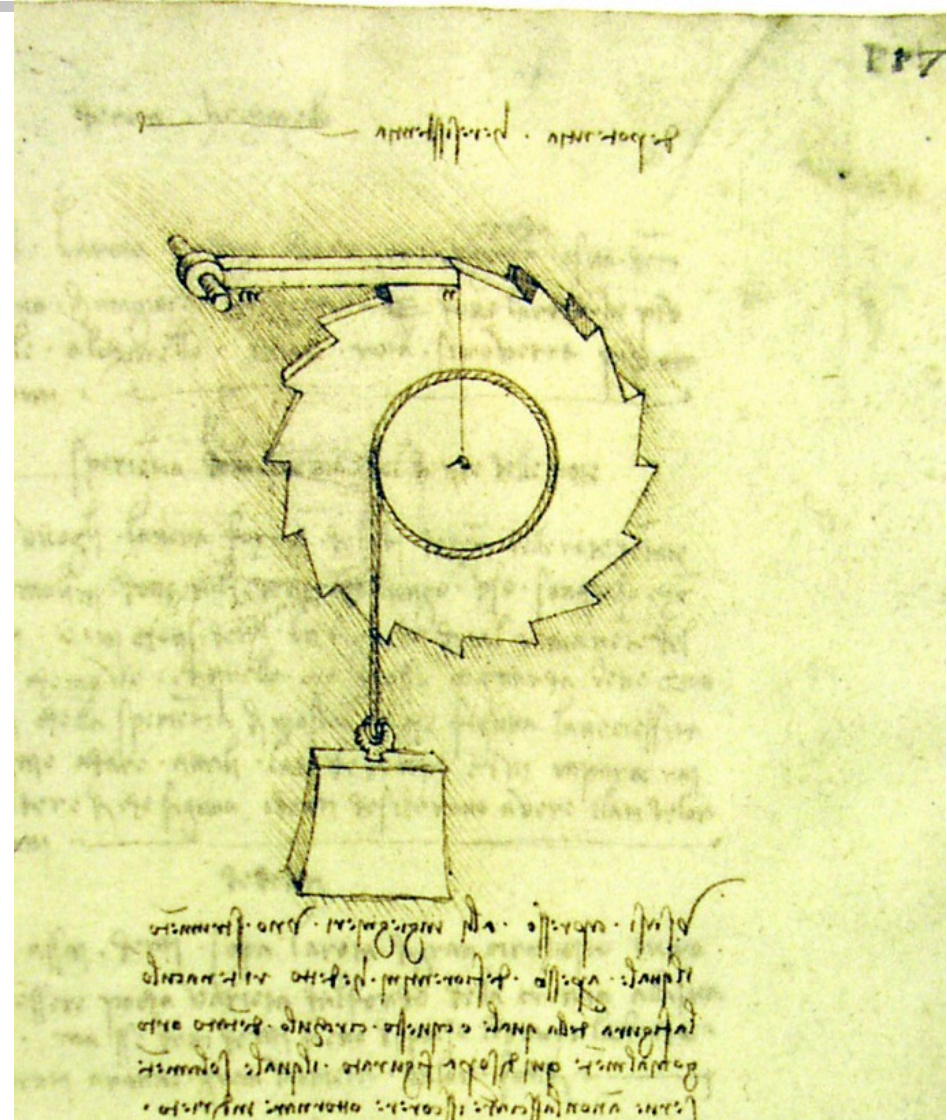
Endless Screw Mechanisms



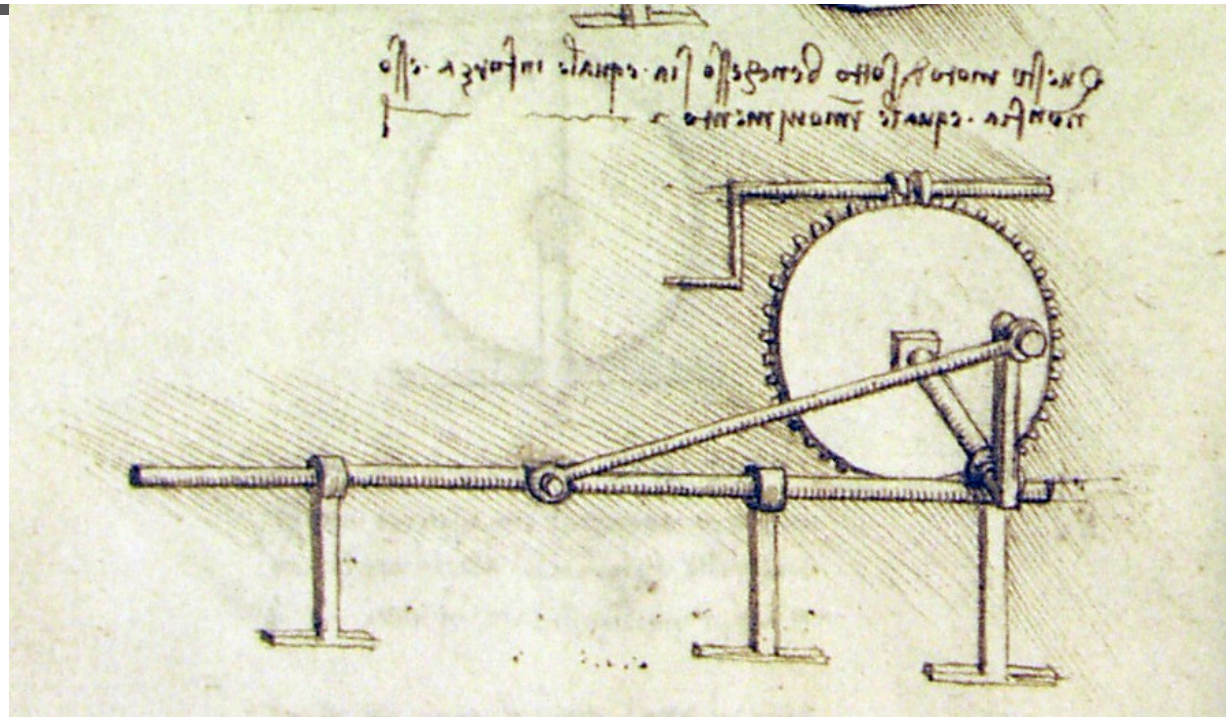
Gear Mechanisms of Rx and LdV {c. 1870, 1470}



Ratchet Mechanisms of Rx and LdV {c. 1870, 1470}



Slider Crank Mechanism: Codex Madrid



Influence of Siena Artist-Engineer Francesco Di Giorgio On Leonardo da Vinci



Francesco di Giorgio Martini (1439-1501)

Born Siena, 1439

Baptized; Francesco Maurizio di Giorgio Martino

May have been apprenticed to Lorenzo di Pietro known as Vecchietta (1410-1480)

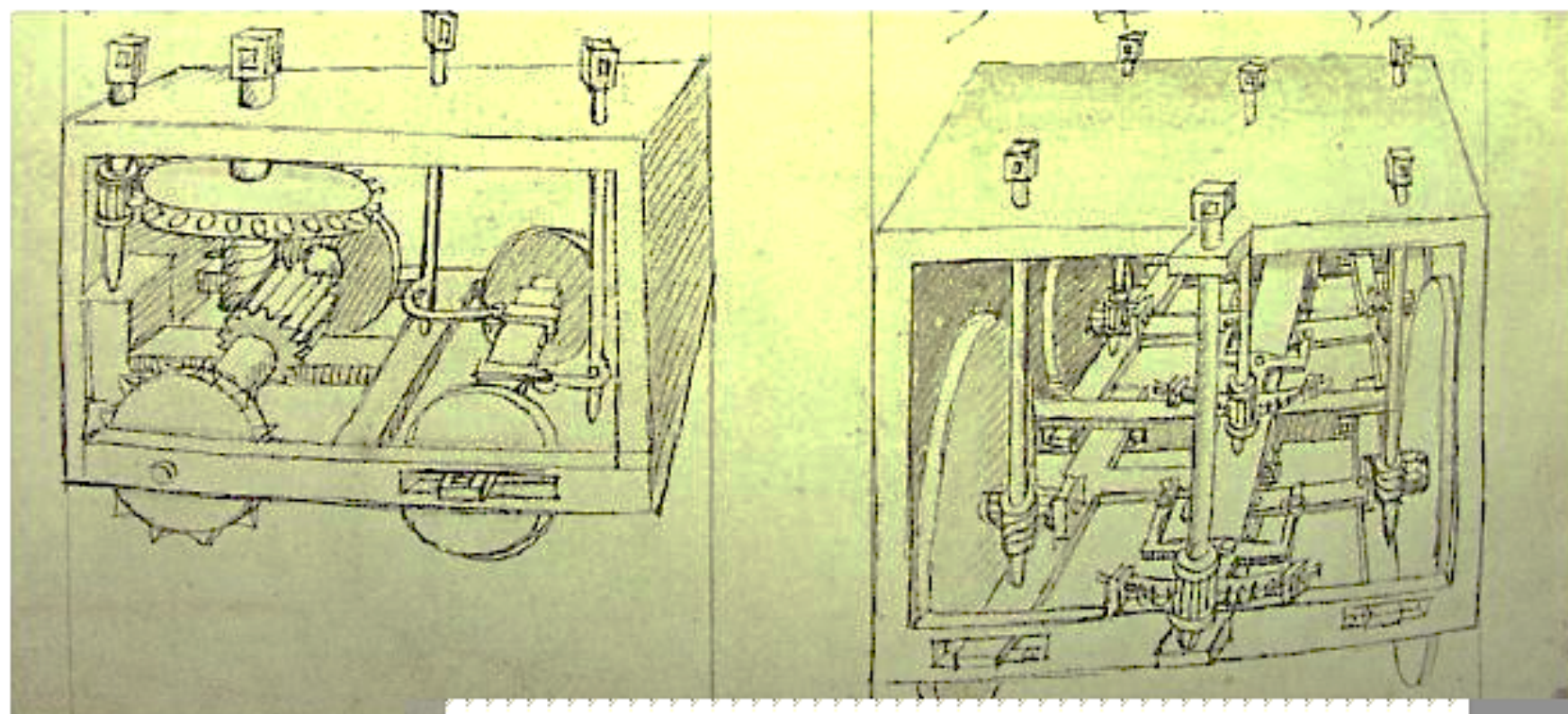
Worked in the service of Duke Federigo da Montefeltro, Urbino in the Marches

Designed and built 136 military fortresses e.g. San Leo and Sassocorvaro.

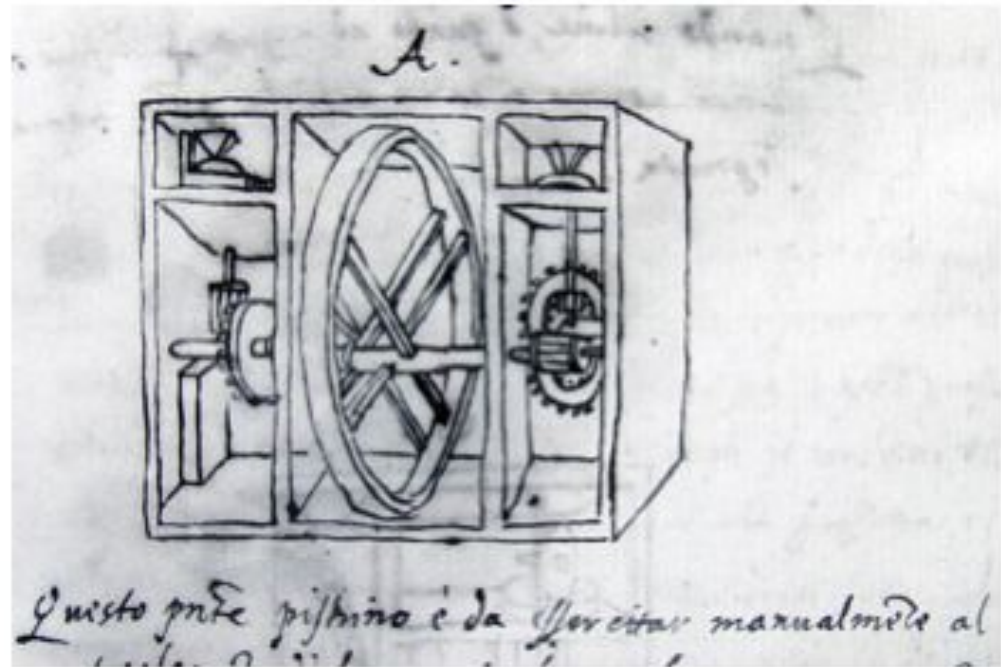
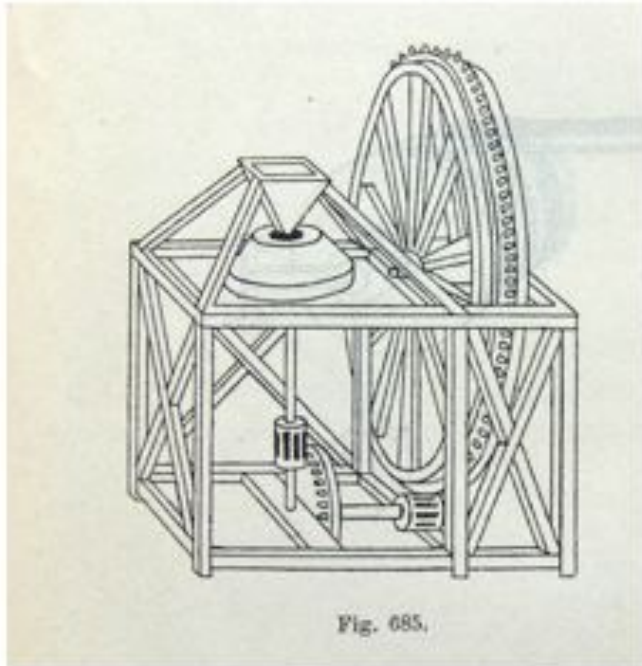
Met and worked with Leonardo da Vinci in Pavia .1490.

Francesco di Giorgio Martini

Wheeled Vehicles

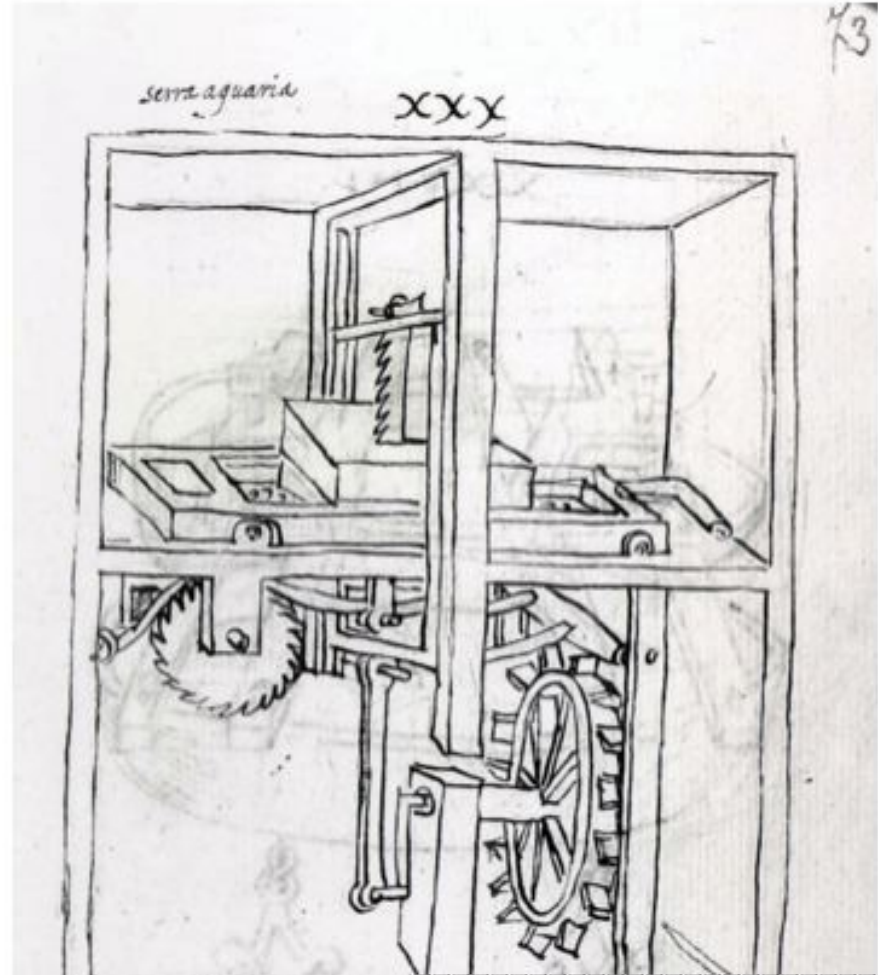


Comparison of Mill Design of Leonardo and Francesco di Giorgio



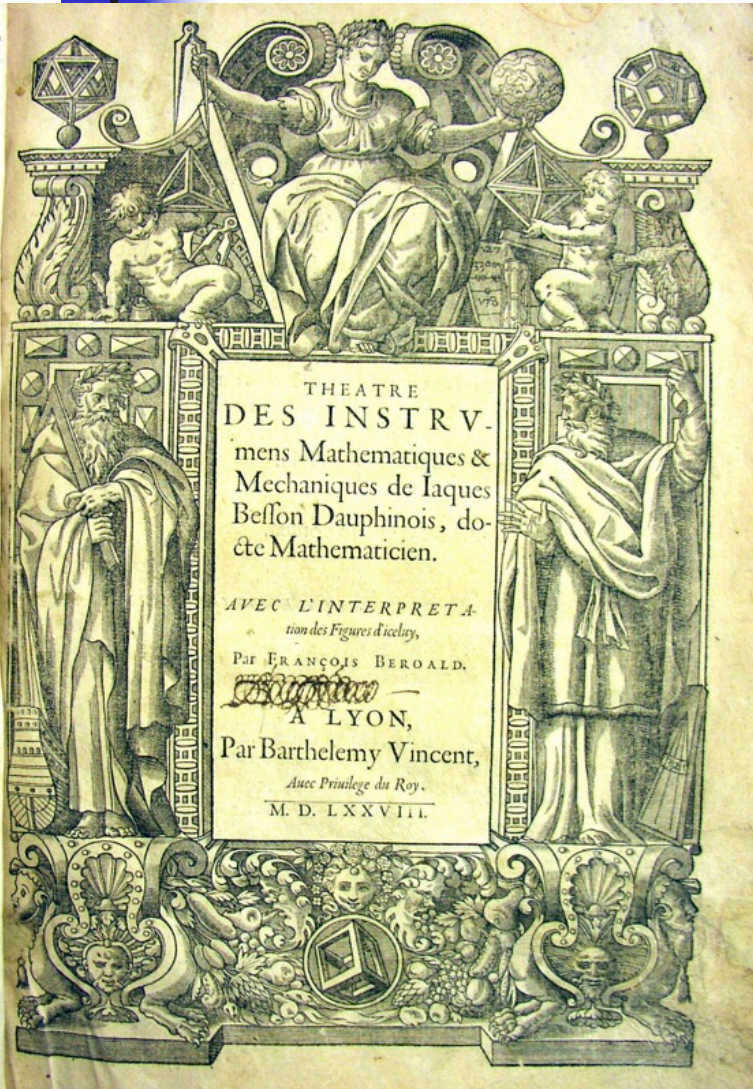
Design for a Lumber Cutting Machine 15th C.

Francesco
Di Giorgio Martini:
Crank;
Ratchet;



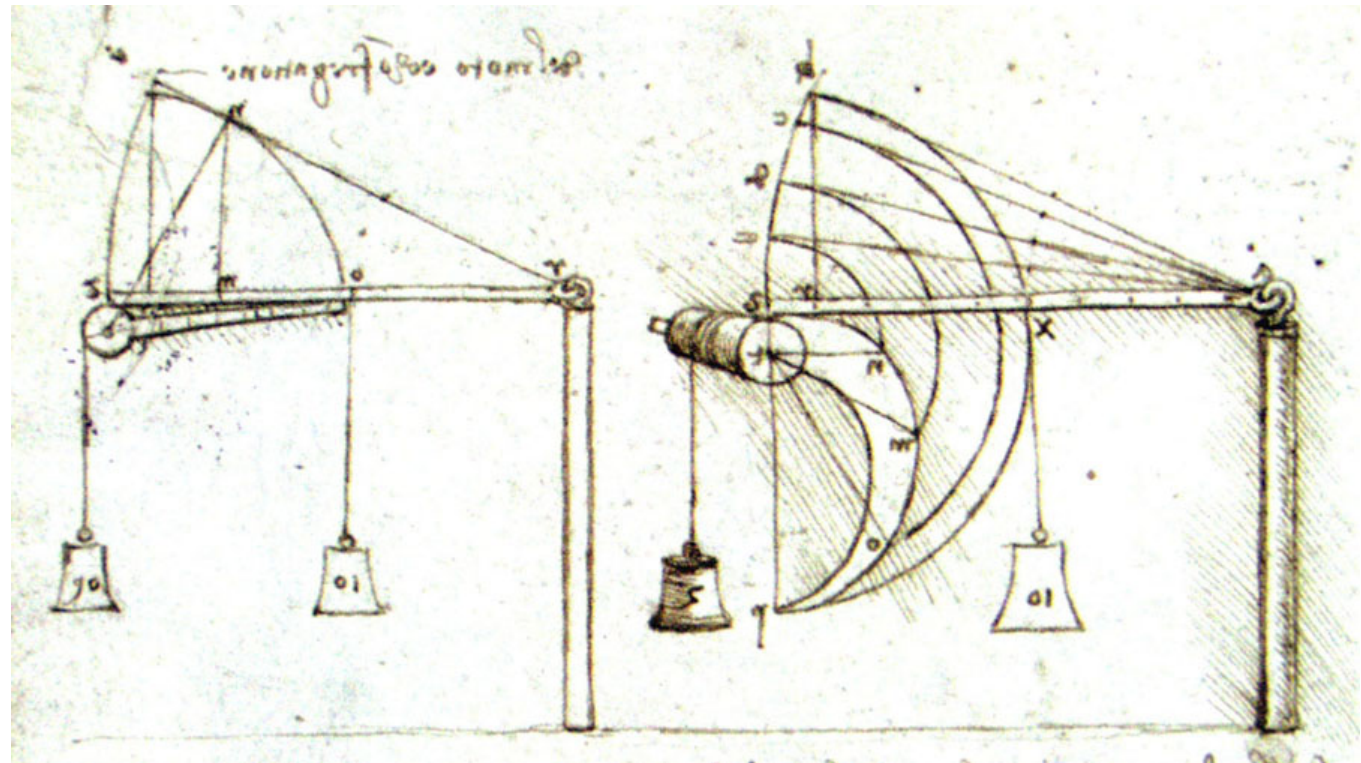
Theatre of Machines Books

Besson 16th C and Borgnis 19th C.



Origins of Concepts of Velocity and Accelerations in Mechanisms

Leonardo's
apparent use of
'path points' or
'roulettes' in
the motion of a
lever
mechanism.



Four Bar Kinematic Chain- *Crank Rocker Mechanism*

Cornell Reuleaux Model Collection



Kinematic Motion of a Spherical 4 Link Mechanism: Cornell Reuleaux Model Collection



Endless Screw Mechanism:
“Worm Drive” – Motion about Two Perpendicular
Axes



Toothed Wheel Mechanisms:

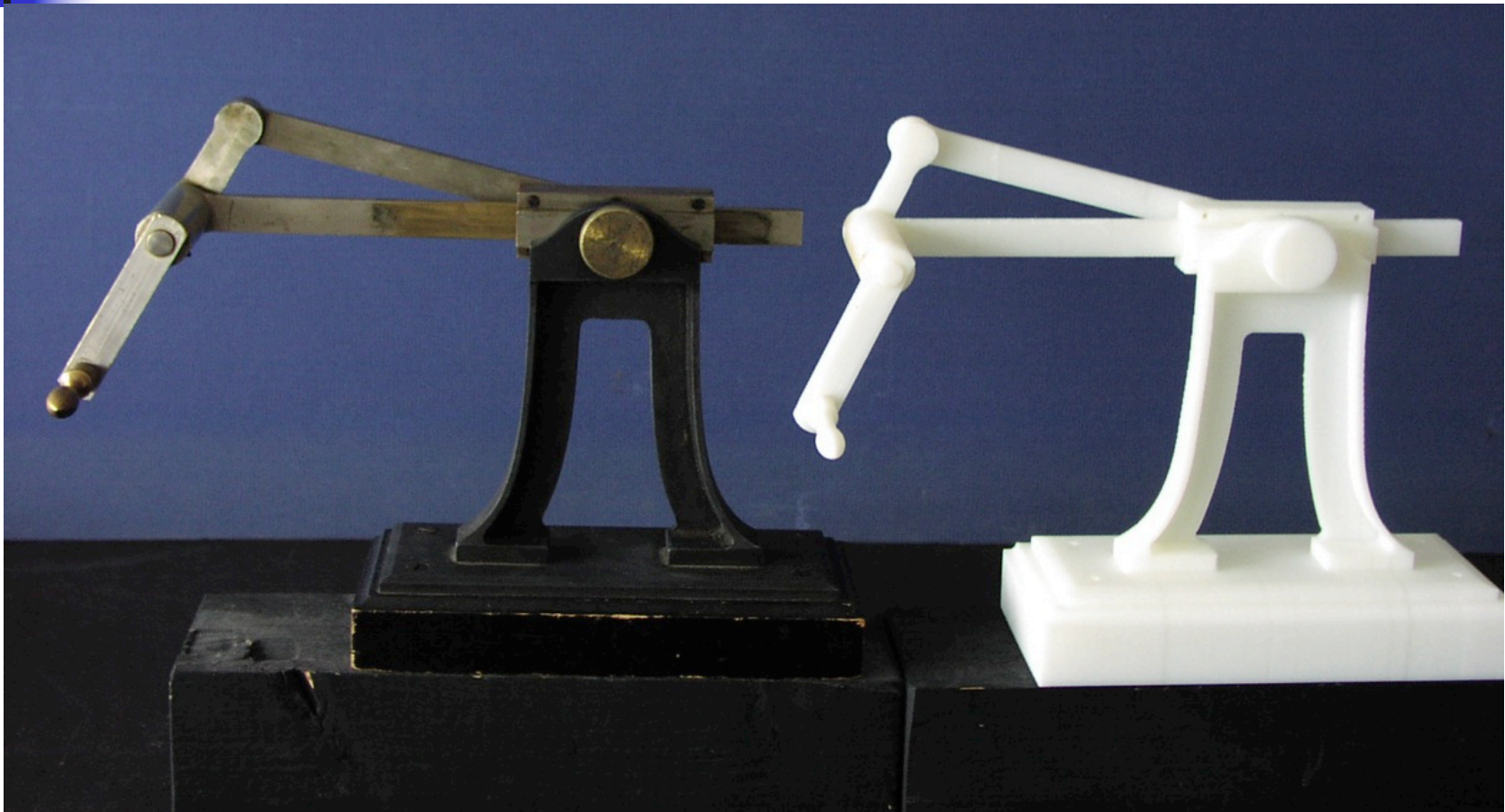
Planetary Gears : Sun: Planet: Ring Gears

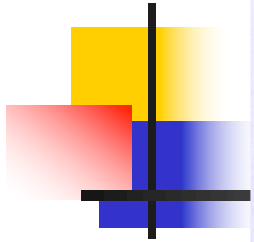


MAE 225 April 2007

Mechanical Engineering - CAD and Rapid Prototyping: 3D Printing the History of Machines:

Professor Hod Lipson, Cornell University

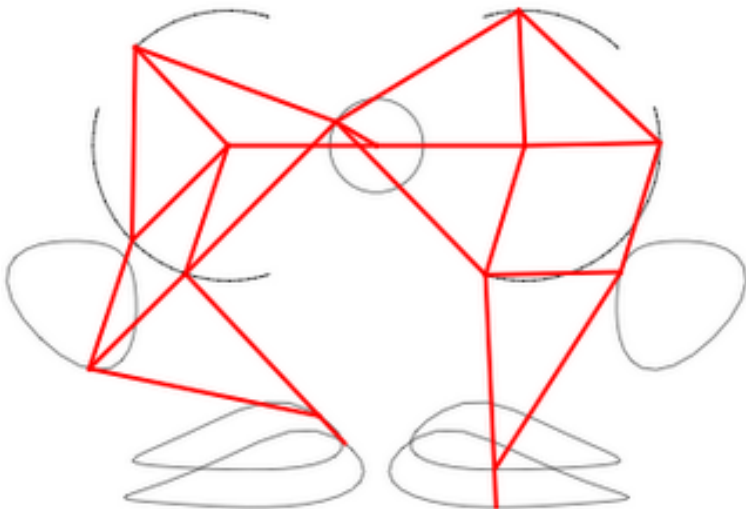
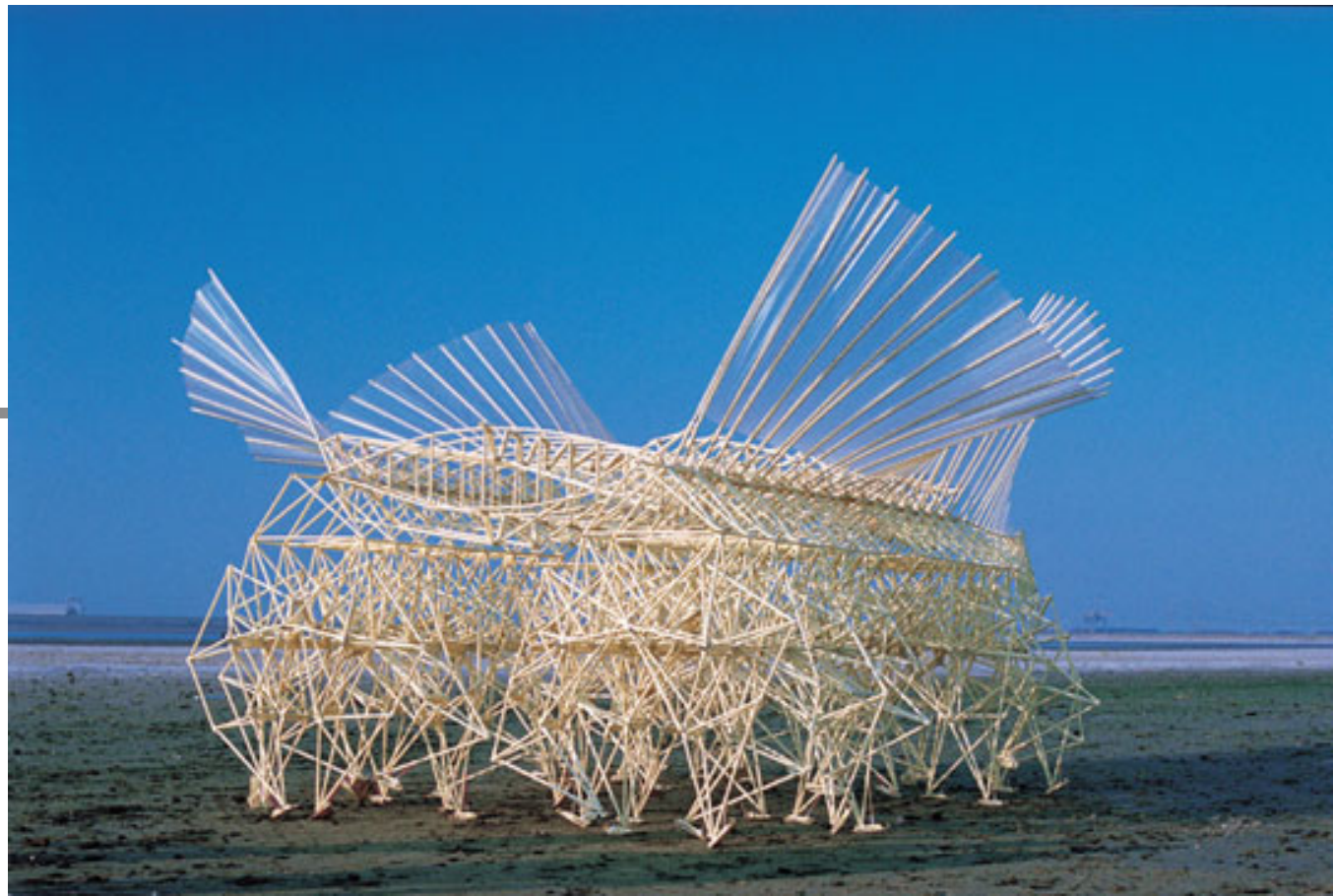
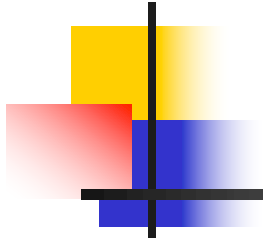




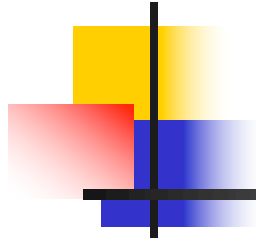
MAE 225 April 2007

The Machine as Art





Theo Jansen's Strandbeest:
8 Link mechanism of Grubler



Website for Kinematic Mechanisms

KMODDL: Kinematic Models
for Design Digital Library

<http://kmoddl.library.cornell.edu>

400 mechanisms, Movies, Photos, CAD,
simulations and rare machine books.

Rapid prototype downloads of models.

Leonardo da Vinci and Dynamics of Machines

Clock escapements

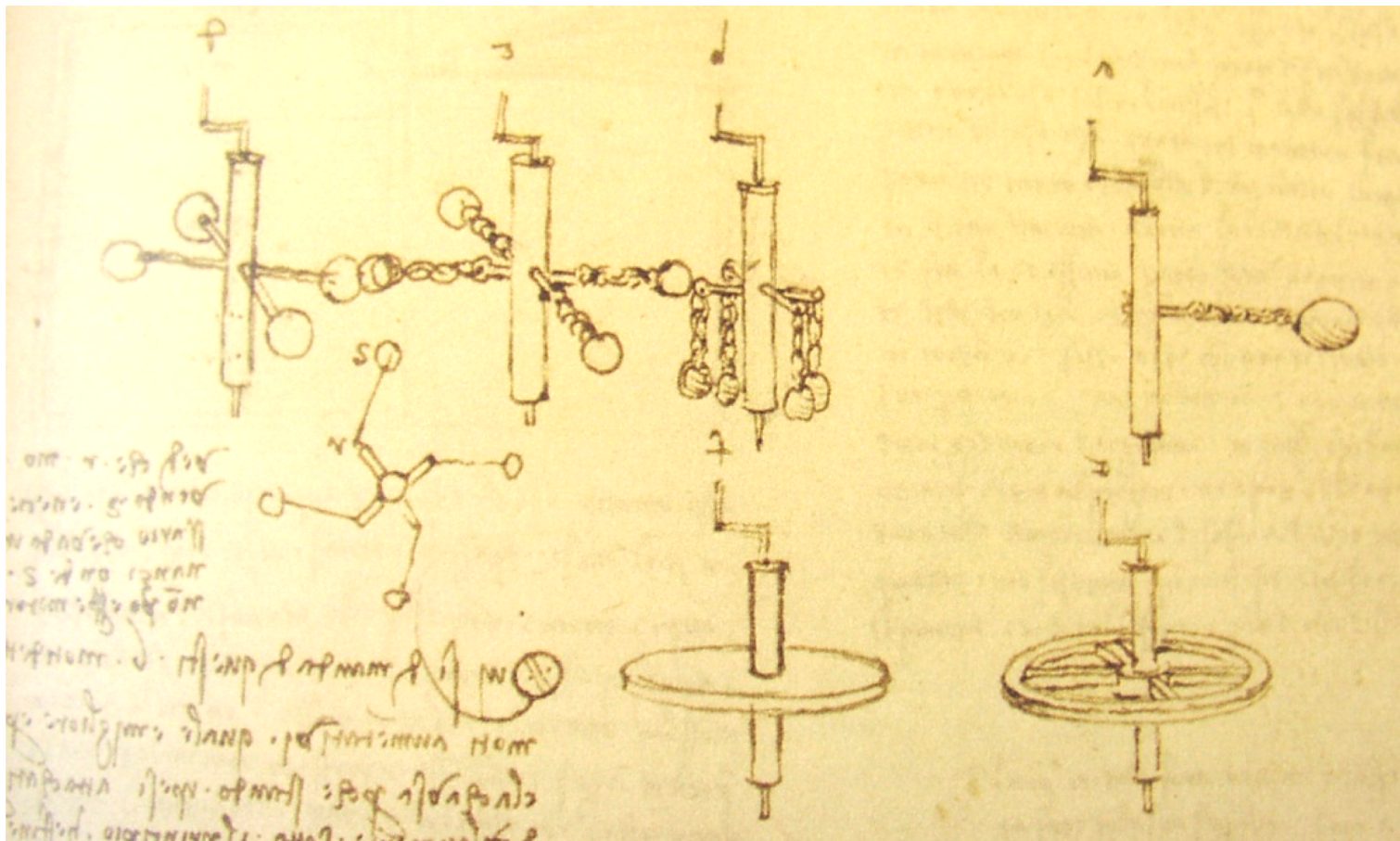
Trebuchets

Flywheels

Perpetual motion wheel

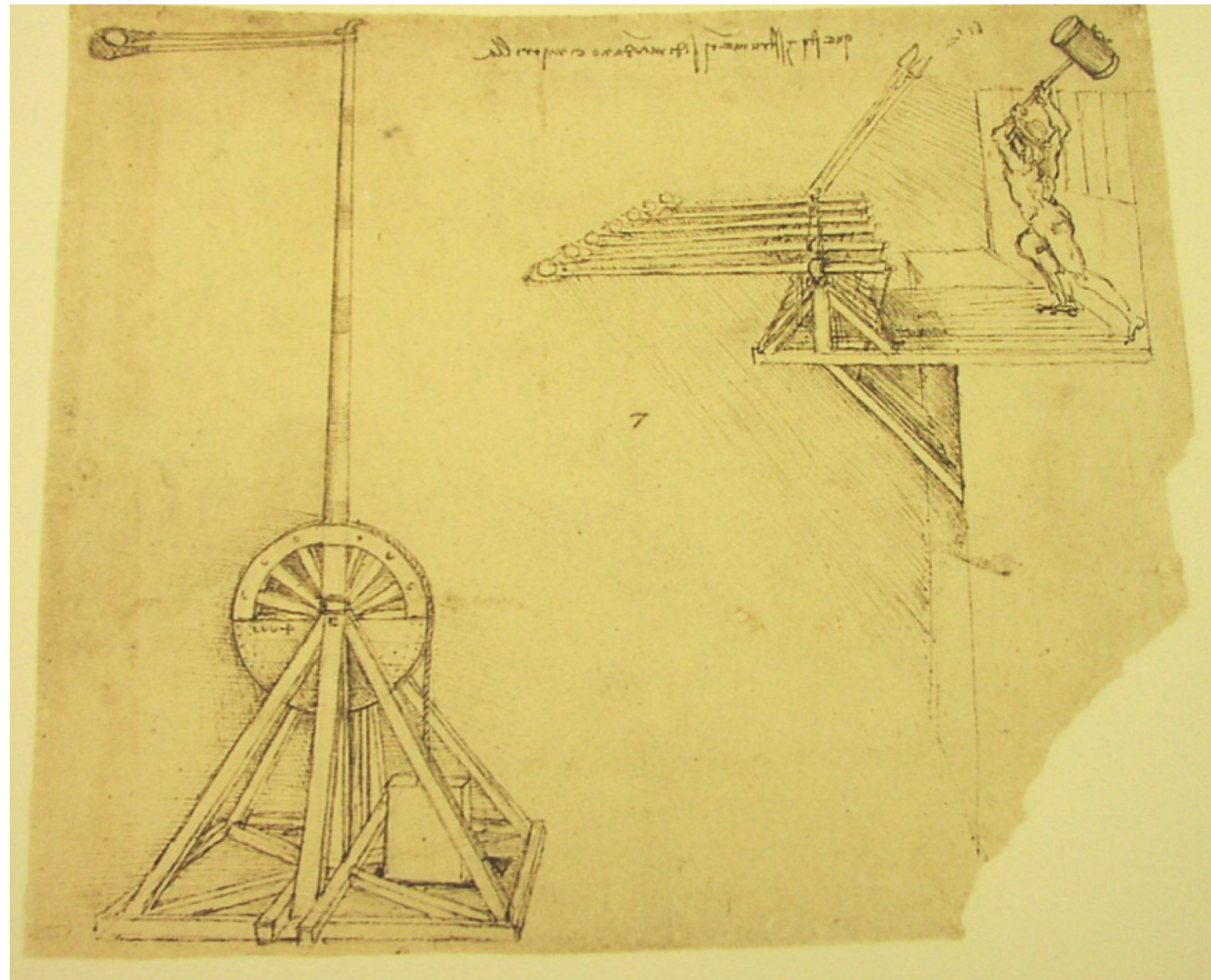


Flywheels in Leonardo's Codex Madrid



Trebuchet: Military Slingshot

Leonardo's Codex Atlanticus: Double Pendulum



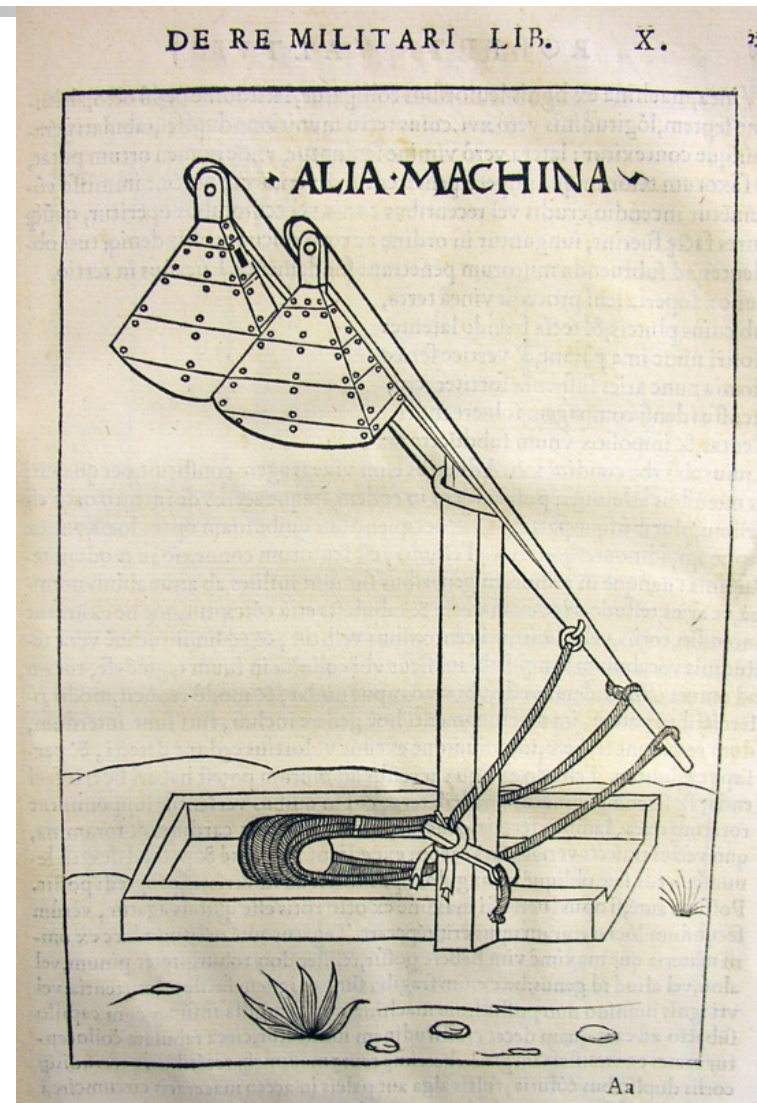
Trebuchet of Roberto Valturio: 1472

Roberto Valturio [1405 - 1475]

De Re Militari

One of the first military uses of the double pendulum;

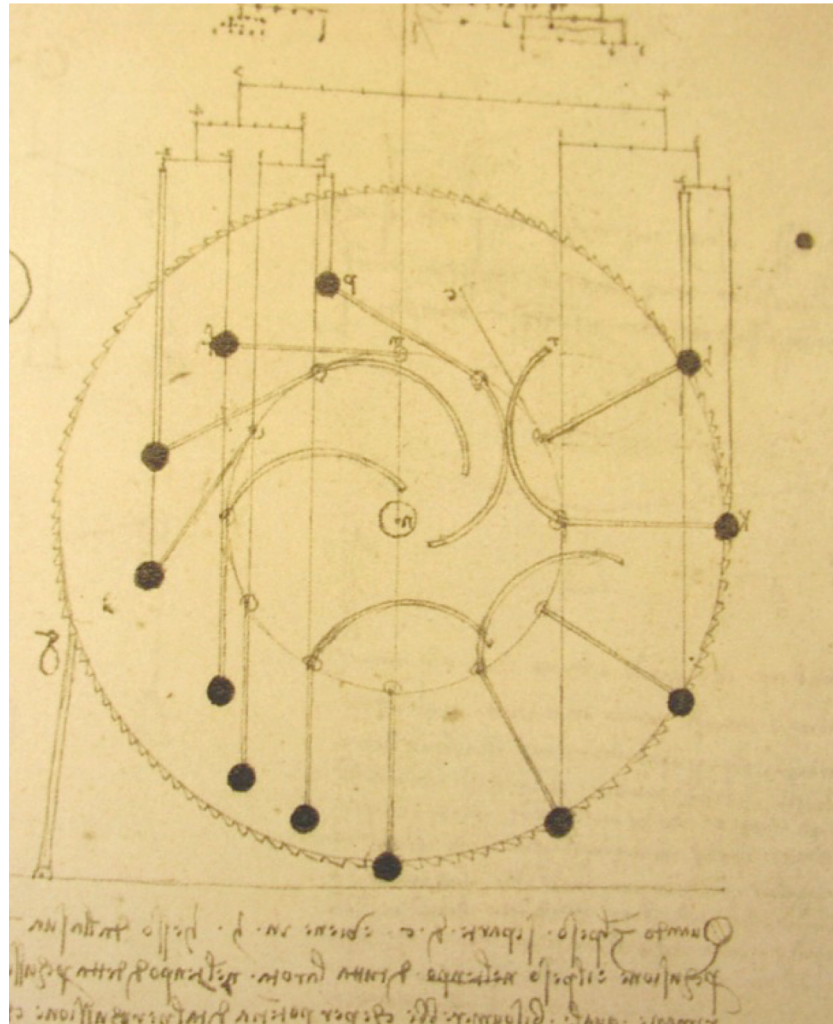
Predates Leonardo's trebuchet.



Perpetual Motion Wheel

L. Da Vinci

Codex Madrid





Perpetual Motion Wheel

Leonardo da Vinci:

“Among the superfluous and impossible **delusions of man** there is the search for continuous motion, called by some **perpetual wheel**. For many centuries almost all those who worked on hydraulic and war machines, and other subtle engines, dedicated much research and experimentation to this problem, incurring great expense. But finally, the same always befell the alchemists: **for a small detail everything was lost.**”

[*Codex Madrid I*, Folio O recto; transl. L. Reti.]

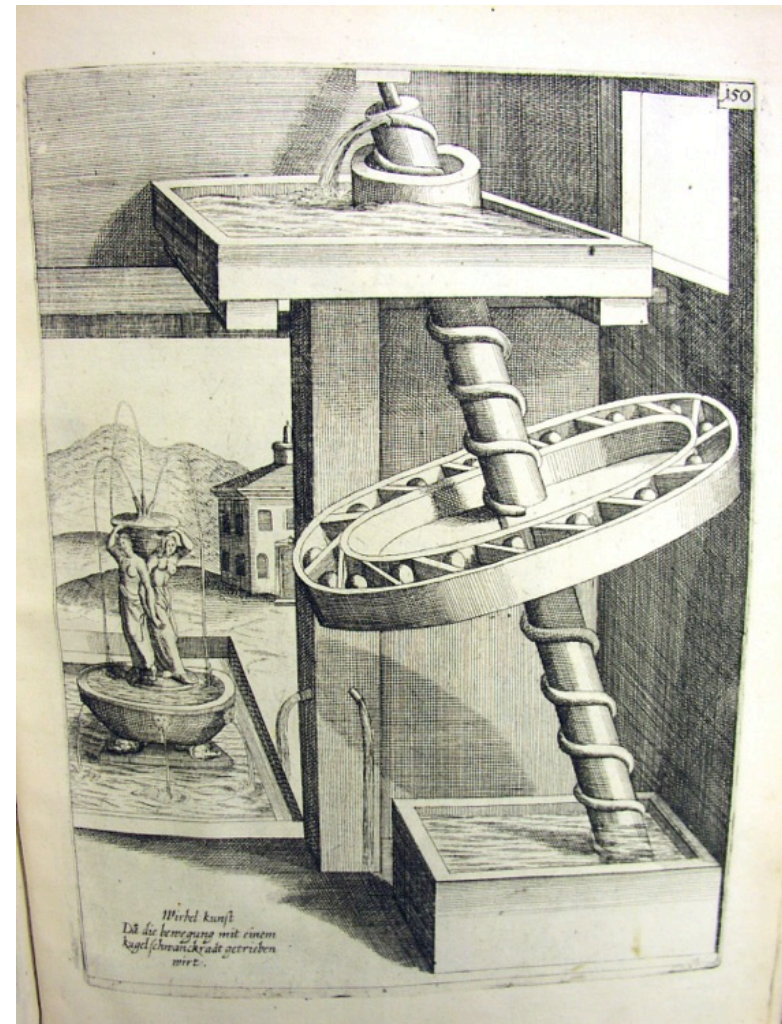
Böckler's Perpetual Motion Machine: 1661

Georg Andreas Böckler [1648-1685]

Theatrum Mechinarum Novum

[Newton's *Principia*, 1686]

Absence of a theory of conservation of energy for machines.

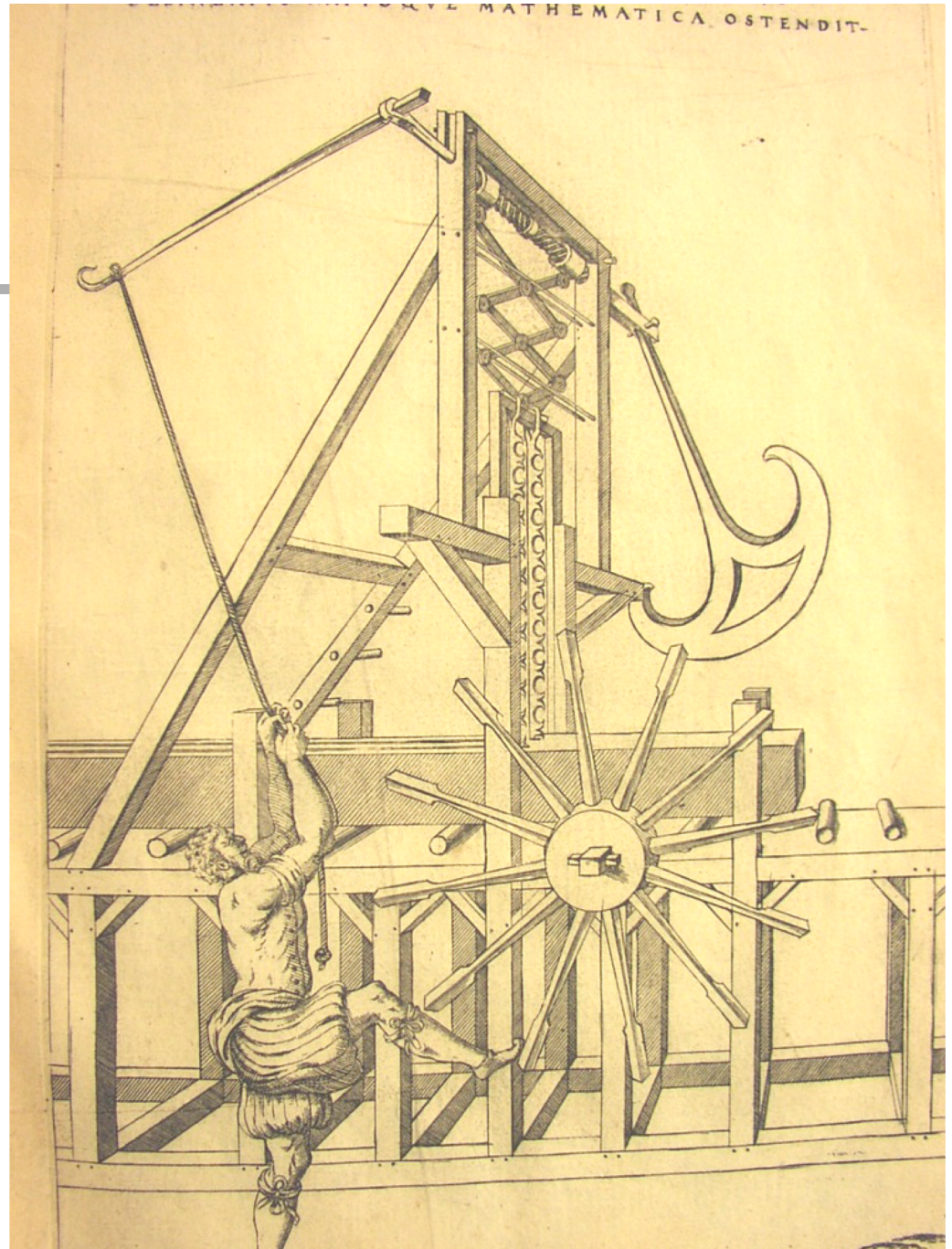


“Theatre of Machines” Books

Besson's Pendulum

(c. 1569)

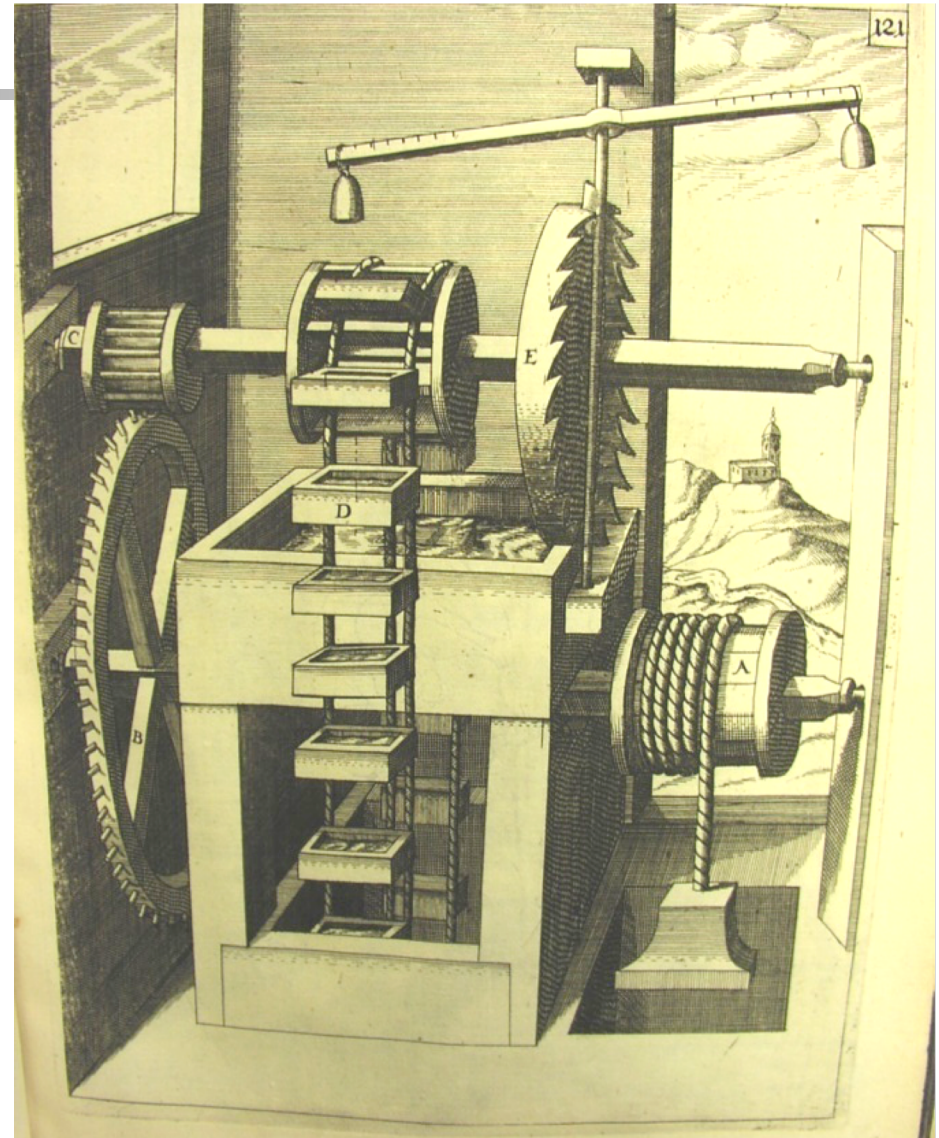
Human resonance
excitation drives the
pendulum whose
inertia moves the
mangle and the
saw.



Böckler's Pump Escapement

(c. 1616)

Verge and foliot escapement used to control the weight driven torque and the speed of the chain of pots pump.



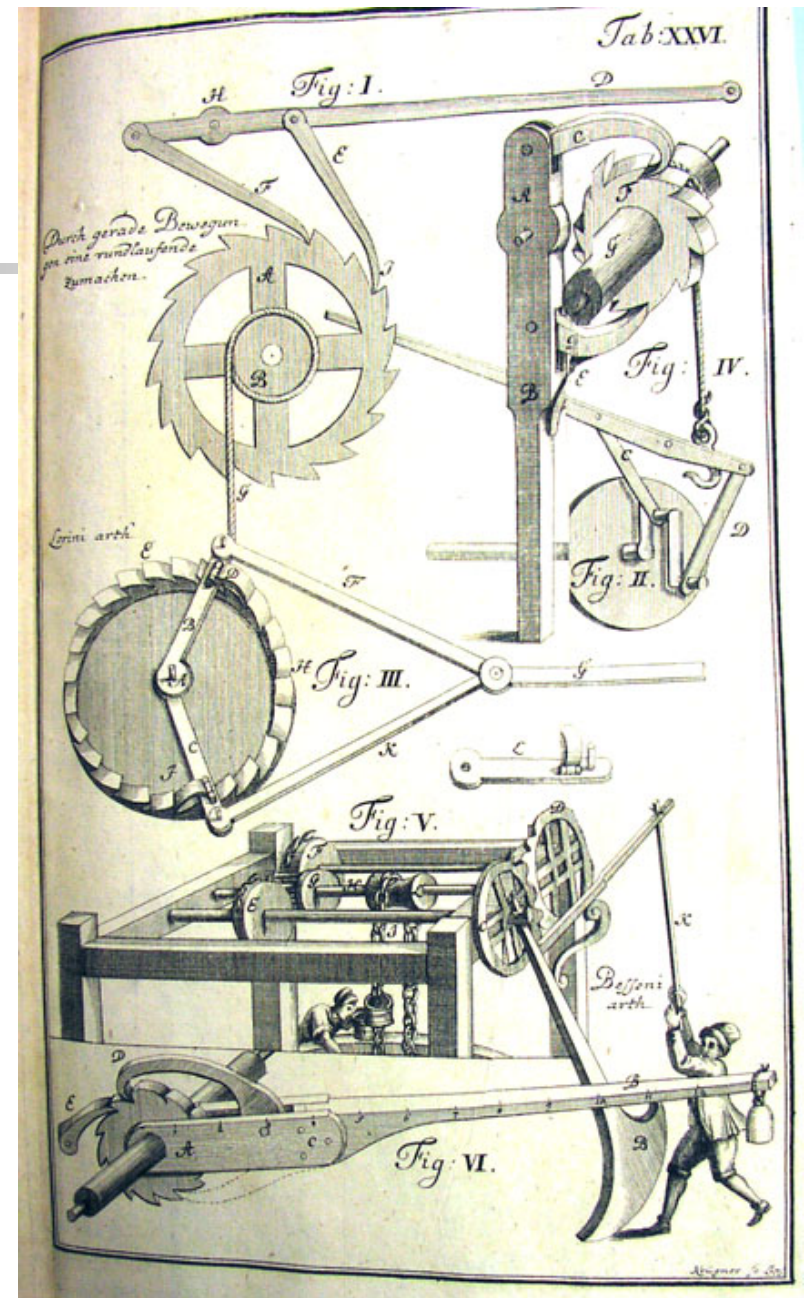
Jacob Leopold [1674 - 1727]
'Theatre of Machines' Book 1724

Theatrum Machinarum Generale

This book was studied by James Watt.

This plate shows ratchet mechanisms as well as a pendulum excited mechanism.

This book also influenced the theory of machines ideas of Franz Reuleaux.



Chinese and Renaissance Origins of the Gimbal and Gyro Mechanism

Drawing of Gimbals

Mechanism by

Leonardo da Vinci

c. 1490, *Codex Madrid*

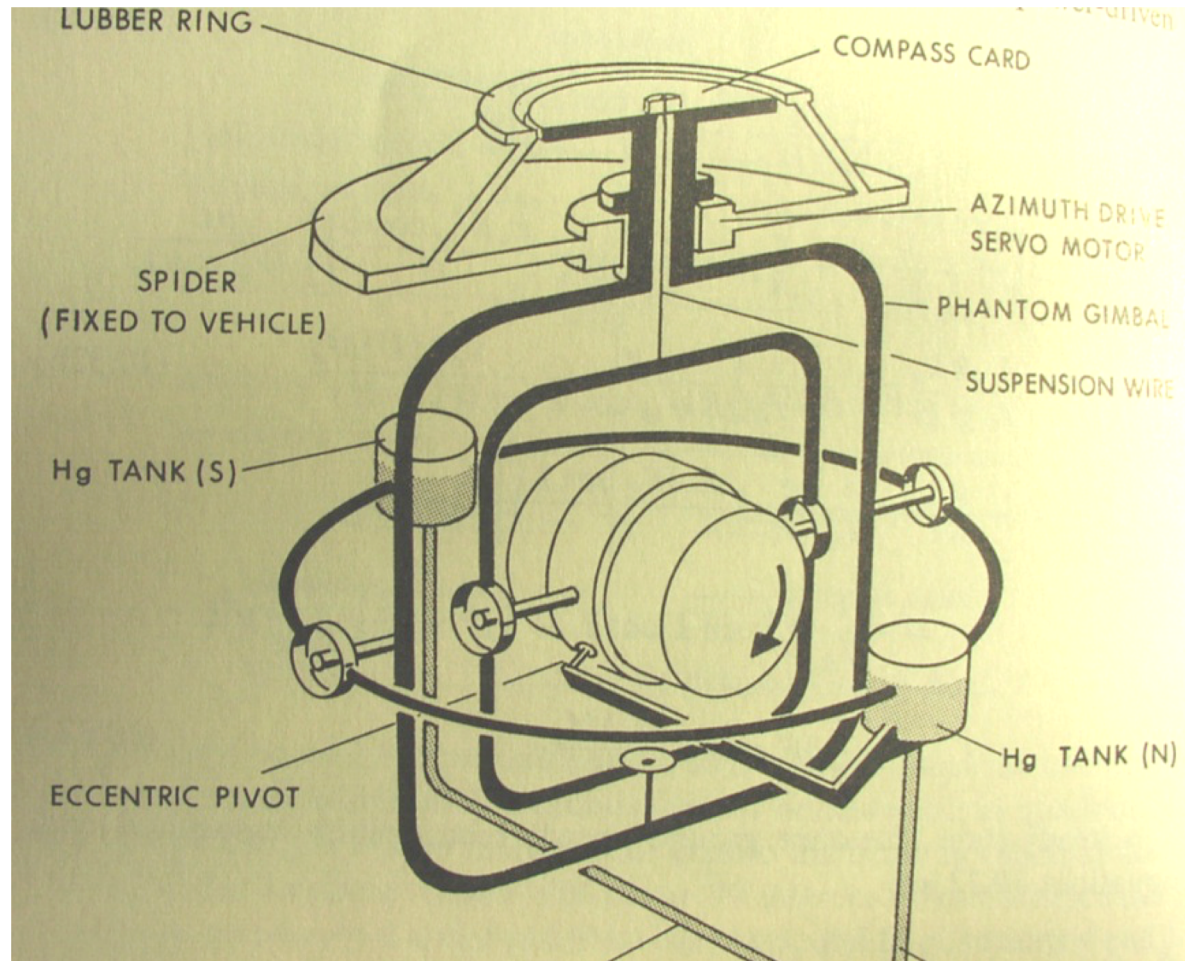


Gyroscopes

Foucault, 1853

H. Anschütz,
1908

Elmer Sperry,
1911

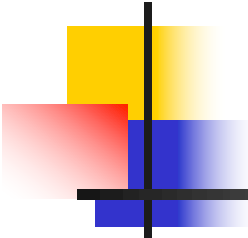




Branding of Leonardo da Vinci

“da Vinci” Robotically
assisted Surgical
System



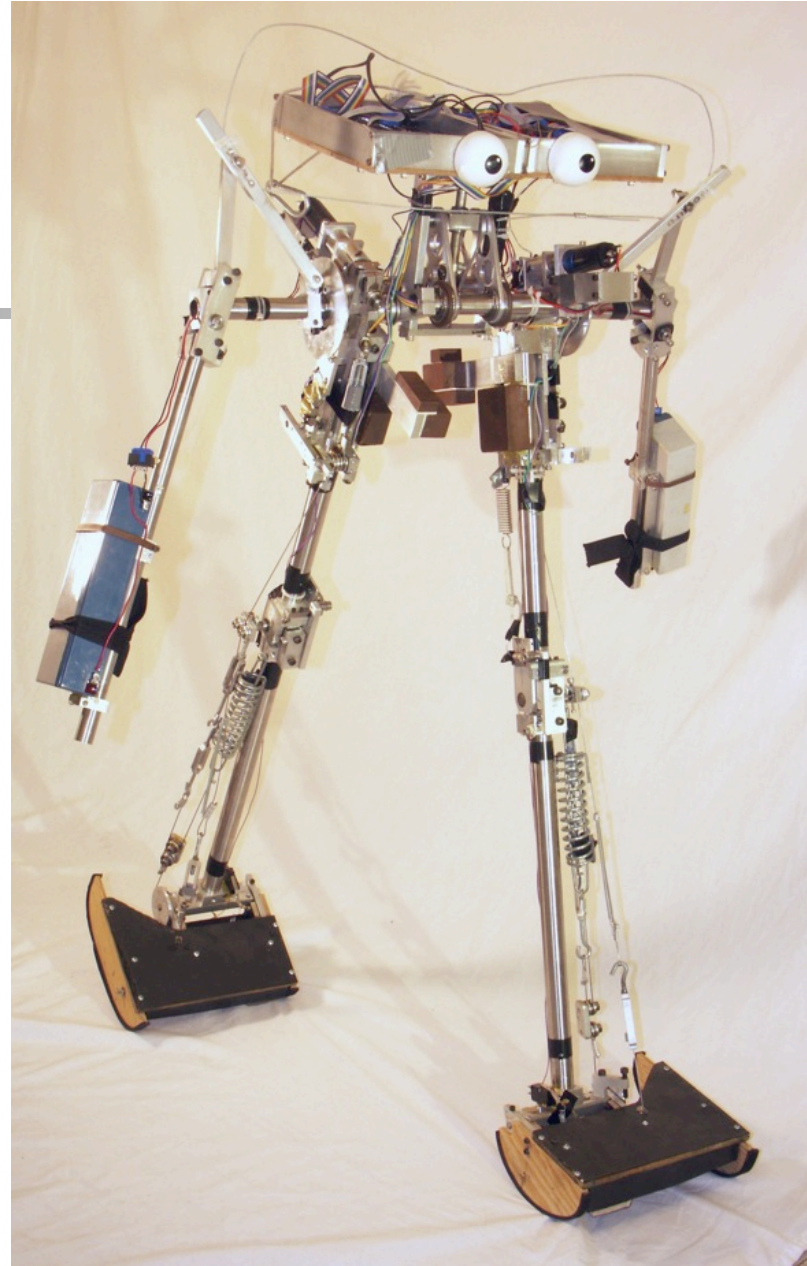


Mark Rosheim:
Book claiming
Leonardo designed
automata walking
machine:
Leonardo's Lost
Robots [2006]

Walking
Machines:

Prof. A Ruina

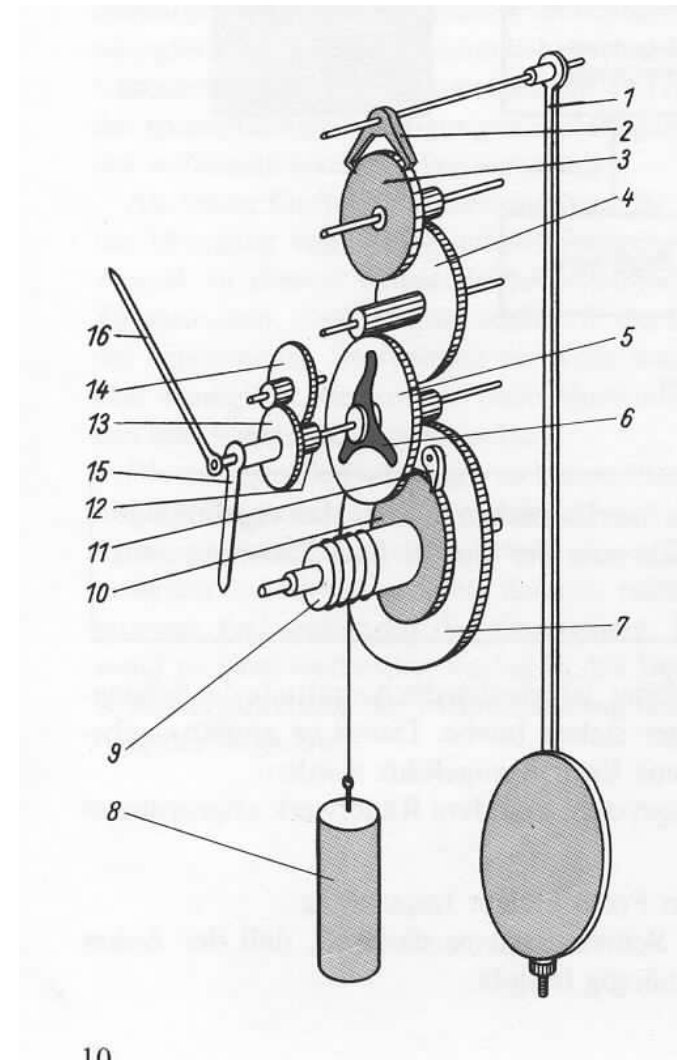
Cornell
University



Leonardo designed components for clocks

Components of Mechanical Clocks:

1. Pendulum
2. Anchor arm of escapement
3. Escape wheel
4. 5. 7. Parts of gear train
8. Drive weight



From Martinek and Rehor

Mechanische Uhren, 1996

Clock Escapement Model of Franz Reuleaux

Anchor escapement

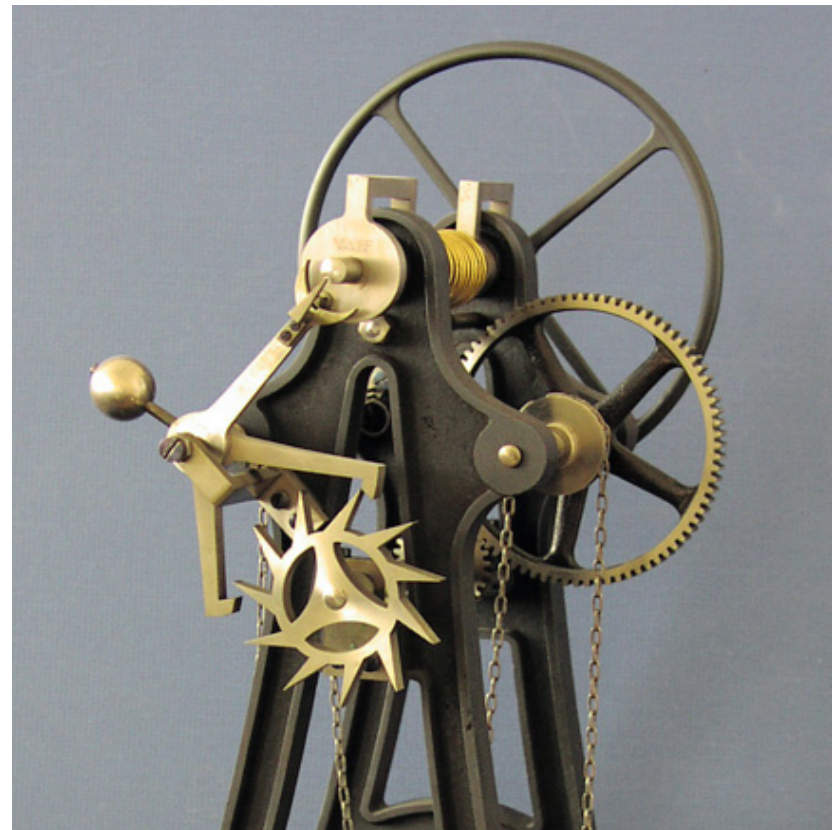
See Reuleaux's kinematic model collection at Cornell University online at;

<http://kmoddl.library.cornell.edu>

Or GOGGLE; KMODDL

Kinematic Models for Design Digital Library

Over 400 kinematic mechanisms online/

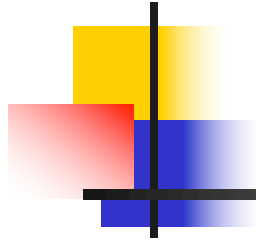




Leonardo on Invention [c.1490]

“And if they despise me **who am an *inventor*** how much more should blame be given to themselves who are **not inventors but trumpeters and reciters** of the work of Others.”





Art Science and Invention

- Are the processes in art and engineering similar or different?
- Are the processes in scientific discovery similar or different from engineering invention?

*'Waiting for a
Theory'*

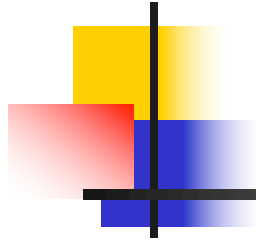
White Oak,
120 years old
5 feet
1991

From a white oak tree taken
down to build the "Theory
Center" Building, Cornell
Campus, now Rhodes Hall.

October 2009







Francis &
“Saint Francis”:
Walnut
2008

October 2009





Moon's 12 Steps of Creativity in Art and Engineering

1. History-Memory: What went before?
2. Learning Skills: Technique, practice and patience.
3. The Quest: A vague vision of a goal or process.
4. Gathering Facts and Ideas: Sketches, little notes, yellow pads.
5. The Struggle: Passion, discipline and order.
6. Serendipity: Expect some chance or chaos.
7. Cross Stimuli: Many projects are good.
8. Sweating the Details: Boring but necessary; 100,000 chips.
9. Recognizing Quality and Originality: When is it done?
10. Presentation: offering the work. What do others think?
11. Once is Not Enough: Entropy lives; Can you do it again?
12. Pass It On!: Teach another, memory again.

FCM



Summary

- The Creation of machines reaches back to **antiquity**.
- Kinematics of machines began in time of Leonardo
- Analytical dynamics matured by the early 19th C.
- Modern Theory of Machines incorporates analytical methods of dynamics, chaos theory, optimization and mathematics of synthesis as well as multi-scale physics.
- The invention of machines is a societal creation.
- The creation of machines incorporates aesthetics as well as science.



New Book

New Springer
Series: **History of
Machines and
Mechanisms**

