

THE AUTOMATON THEATER

by

Zafrios Xagoraris

B.A. Athens School of Fine Arts, 1988

Submitted to the Department of Architecture
in partial fulfillment of the requirements
for the degree of

Master of Science in Visual Studies


at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY


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Signature of Author


Zafrios Xagoraris, Department of Architecture
May 10, 1991

Certified by


Otto Piene
Director, Center for Advanced Visual Studies
Thesis Supervisor

Accepted by


Otto Piene
Chairman, Departmental Committee
for Graduate Students

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Abstract

Hero of Alexandria was a Greek geometrician, engineer, and inventor who lived in Alexandria probably during the first century A.D. He wrote in Greek a number of theoretical treatises revealing a thorough knowledge of geometry, mechanics, optics, and pneumatics. Being more interested in the applications of his theoretical principles than in the principles themselves, Hero is known as the inventor of a number of ingenious devices based on principles of pneumatics, mechanics, and optics. The objective of this thesis is to evaluate Hero's work from an artistic viewpoint. To this end, it focuses on devices described in three of Hero's treatises, *Pneumatica*, *Catoptrica*, and *Automatopoietica*, in order to identify their artistic value and artistic novelty. Hero's influence on subsequent artistic-technical work, and in particular on the contemporary automaton theater, is also discussed. Finally, considerations are added in relation to a new project.

Thesis Supervisor: Otto Piene,
Director, Center for Advanced Visual Studies

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THE AUTOMATON THEATER

1 Introduction

Hero of Alexandria was a Greek geometrician, engineer, and inventor who lived in Alexandria probably during the first century A.D.. Little is known of his life. After the death of its founder Alexander the Great, Alexandria was ruled by the Dynasty of Ptolemy, one of Alexander's generals and the governor of Egypt. During that period a great university by the name of "Museum" (from the nine muses) was set in operation. The Museum also housed the famous Library of Alexandria (see Figure 1). Two of the most known thinkers who worked in the Museum were Archimedes and Euclid. The great engineer Ctesibius, who at a young age invented a mechanism to raise and lower a mirror in his father's barber shop, also worked in the Alexandrian school. His written works, however, were destroyed during the fire that burnt down the Library of Alexandria. Ctesibius influenced Hero's work profoundly, and he may have indeed been Hero's teacher. In fact Hero is referred to as Hero of Ctesibius in some manuscripts.

Hero wrote in Greek a number of theoretical treatises revealing a thorough knowledge of geometry, mechanics, optics, and pneumatics. His most important geometric work, *Metrica* describes methods for finding areas of various plane figures and volumes of various geometrical solids. It includes the derivation of his formula (known

as Hero's formula) for calculating the area of a triangle. Hero's other geometrical works are *Definitiones*, *Geometrica*, *Geodaesia*, *Stereometrica*, *Mesurae*, and *Liber Geëponicus*. Related to his geometric work is the *Dioptra* that studies the *dioptra* (dioptra), a surveying or spying instrument, and the *Catoptrica* that studies light reflection. What remains of Hero's work on mechanics are *Mechanica*, *Pneumatica*, *Automatopoietica*, *Belopoeica*, and *Cheirobalistra*. Only portions of other treatises by Hero remain. One on water clocks and another, a commentary on Euclid's *Elements* are quoted in later works. Indeed, most of his treatises have survived in later Latin or Arabic translations.

Being more interested in the applications of his theoretical principles than in the principles themselves, Hero is known as the inventor of a number of ingenious devices based on principles of pneumatics, mechanics, and optics. My thesis studies the artistic elements in three of Hero's treatises, *Pneumatica*, *Automatopoietica*, and *Catoptrica* and relates them with later works and notions of art. In *Pneumatica*, Hero describes siphons and a number of devices which perform kinetic events mainly with the power of steam. In *Automatopoietica*, Hero introduces the art of the automaton theater. There, mechanisms mainly operating with the power of descending weights produce an entire automaton performance. In *Catoptrica*, he explains the law of reflection and describes mirror installations (ancient Greek mirrors were made of copper or other metals).

It is not clear which of Hero's ideas are pure innovations. In the introduction

of *Pneumatica*, Hero states that his purpose is to set in order the discoveries of his predecessors and to add to them his own. Also, in the introduction of his chapter on *stata automata* in *Automatopoietica*, Hero sets as his goal to improve Philo of Byzantium's automaton theater. Nevertheless, Hero's texts is our only direct source describing such mechanical and—I maintain—artistic devices, and hence I discuss them in their own right.

The self-animated figure had always been a dream of many ancient Greek inventors, but only few allegedly succeeded in creating such a machine (e.g., Daedalus). There is some evidence though of the existence of movable puppets in the ancient Greek world. In the “Simile of the Cave” in Plato's *Republic*, people tied inside a cave watch the shadows of objects that lie between them and a fire. Xenophon mentions the *neurospasta*, a kind of marionette show shown in the theater of Dionysus in Athens. Puppets with movable parts have also been found in certain sarcophagi in Egypt. The shadow plays and the marionettes, though not self-animated, were the predecessors of the automaton theater.

When talking about theater in Hero's time, it is useful to know some of the stage machines that were in use during that time. The *eccyclema* was a platform on a rolling mechanism used to present the dead or killed during the performance. The *periaktos* was a turnable prismatic panel with each side painted. The *keraunoskopeion* was a *periaktos* with painted lightings on each side, and the *vronteion* was a machine with rocks falling on a copper plate, creating the sound of thunder. Finally, the *deus*

ex machina was a crane-like device used to elevate actors playing the role of gods.

The remainder of this thesis is conceptually divided into two parts. Sections two, three, and four discuss Hero's *Pneumatica*, *Catoptrica*, and *Automatopoietica* from an artistic point of view, and the rest of the sections discuss the influence and extensions of Hero's work and describe my own project.

2 Pneumatica

For by the union of air, earth, fire, water, and the concurrence of three, or four, elementary principles, various combinations are effected, some of which supply the most pressing wants of human life, while others produce amazement and alarm.—Hero, *Pneumatica*

Pneumatica describes a series of devices powered mainly by heated air (*pneuma* in ancient Greek is the air, or the blowing of the wind, or the breath) whose operation is based on the properties of liquids and in some cases on mechanics. *Pneumatica* was first translated into Latin during the 13th century. Most of the manuscripts date from the fifteenth and sixteenth century during the years of the Renaissance when there was an increasing interest in the ancient Greek civilization. To date we do not know how these devices looked like or whether any of them were ever constructed, though attempts to describe their function and shape exist in illustrations in several medieval, and nineteenth century manuscripts. Nevertheless, I proceed with my artistic analysis based on Hero's descriptive written suggestions and on drawings taken from Bennet Woodcroft's *Pneumatica* [6]. These drawings date from the Renaissance, as well as from the oldest Greek manuscript referring to *Pneumatica* written by Marcianus (516 A.D.). An open question remains as to whether Hero is the inventor of the machines and methods he describes, since in the introduction of *Pneumatics*, he states that his purpose is to set in order the discoveries of his predecessors and to add to them his

own. For example, in the Introduction of Woodcroft's *Pneumatica* it is mentioned that the cupping glass and syringe that Hero describes must have been in use for some time since there have been many references to them in other medical treatises.

Among the other devices there are two that were developed in later centuries and were put to frequent use: the steam engine and the windmill. The steam engine consists of a sphere mounted on a boiler by an axial shaft and having two bent nozzles to produce a rotary motion from the escaping steam (see Figure 2). The windmill, which is described in the device "Altar Organ Blown by the Agency of a Windmill," is composed of a rod with broad arms which, forced by wind, drives a pump (see Figure 3). The pump forces the air out of a box with pipes, thus producing the sound of a flute. This device, besides its later practical applications, has two obvious artistic elements: the construction of a musical instrument and the use of wind to produce music. I next describe in detail three of the devices from *Pneumatica*.

Temple Doors Opened by Fire on an Altar

The purpose of this device is to have a stage door open as soon as fire is lit on an altar. This device consists of a pedestal on which lie a small temple and an altar through which a tube is inserted (see Figure 4). The hinges of the door, which is also on the pedestal, are extended downwards under the pedestal and turn freely on pivots. From the hinges two chains running into one are attached by means of a pulley and suspend a vessel. The mouth of the tube is contained in a globe which lies

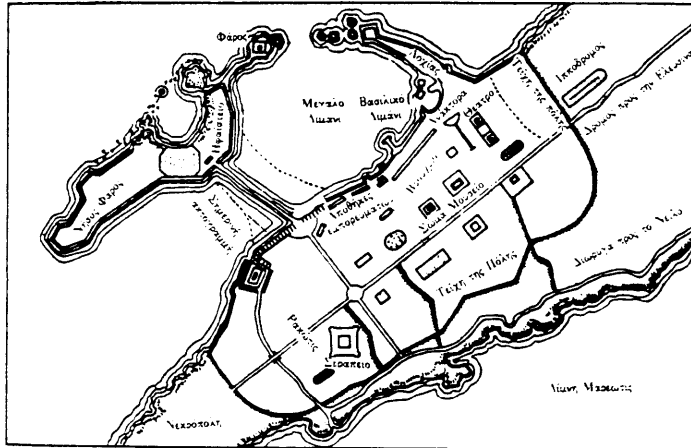


Figure 1: Map of Alexandria

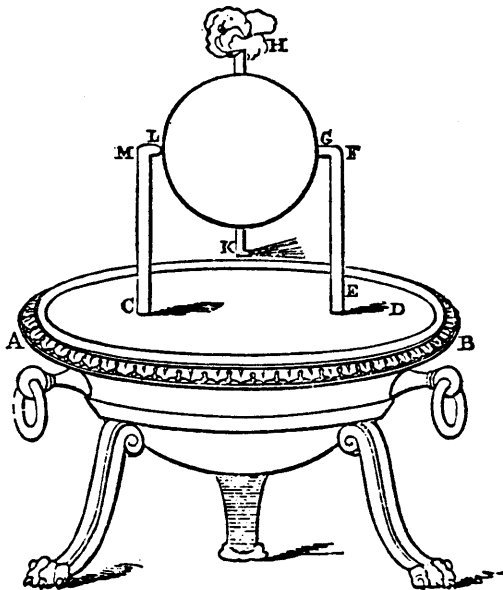


Figure 2: Steam Engine

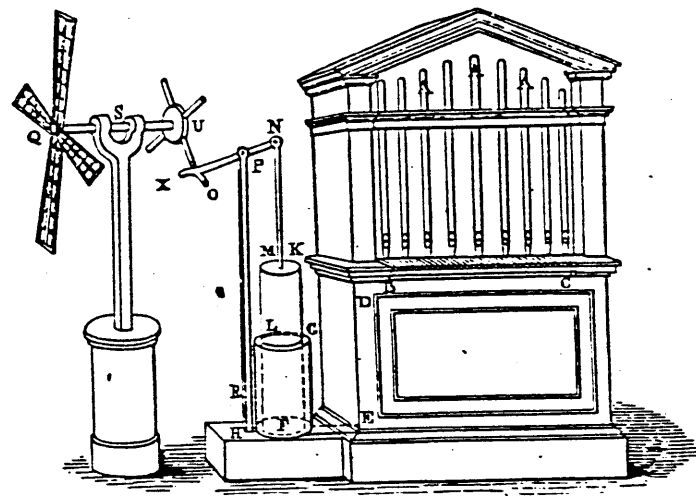


Figure 3: Windmill

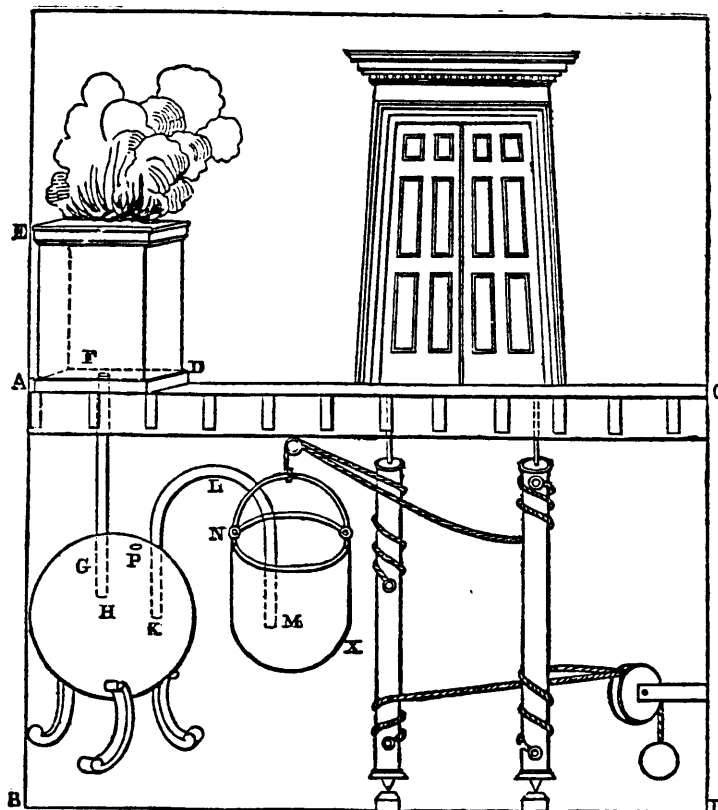


Figure 4: Temple Doors Opened by Fire on an Altar

under the altar and under the pedestal. In the globe is placed a bent siphon whose outer leg leads into the suspended vessel. Through a hole, water can be poured into the globe. Two other chains wound upon the hinges in an opposite direction to the former and are also running into one. The second set of chains is attached by means of a pulley to a leaden weight on the descent of which the doors open.

The operation of the device consists of the following sequence of events. When the fire is lit on the altar, it causes the air inside the altar to expand and to pass through the tube and into the globe. The pressure drives the liquid out of the globe through the siphon into the suspended vessel. The vessel descends due to its increased weight, tightens the chains, and causes the hinges to rotate and the doors to open.

Reversely, when the fire is extinguished the doors shut as follows: The rarefied air escapes through the pores of the globe, and the bent siphon draws up the liquid from the vessel in order to fill the void. As a result, the weight of the vessel decreases causing the vessel to ascend and the hinges to rotate in the reverse direction than before, thus closing the doors. Finally, Hero mentions that in place of water quicksilver can be used because it is heavier than fire and easily disunited by fire.

In his description of the operation of the device, Hero reveals a procedure consisting of several steps whose composition leads to a stand-alone entity. This device manifests a number of poetic elements through the use of the four basic natural elements (fire, air, water, and earth through gravity), and their basic physical properties (eg. the expansion of the heated air, fluid pressure, gravity, and the torsional forces

exerted by the chains). The basic elements by being used as moving powers reveal themselves through their properties.

The happenings have a deterministic duration and a confined size. The fire is lit and extinguished, the weight goes all the way down and up again, the darkness appears and disappears. Each particle has its own mission and acts for a given period of time. The sole purpose of the operation is to cause the fire to open the doors. The fire reveals the inner space of the temple. The sacrifice and the libation leads to revelation and acceptance.

The operation of the device results in a repetitive sequence of extremes. The inner part of the temple is dark. When the fire is lit, the doors open, and the black interior of the temple is revealed. Thus, light creates darkness. The lighting of the altar and the opening of the doors are parts of the same ceremony and lead to each other automatically. The future is repetitive and known in advance. The same holds true for Hero's device "Libations at an Altar Produced by Fire."

The character and meaning of the device as a whole are disclosed to us only after we have encountered, one by one, all the parts of what obviously was planned as a succession of events. To create such an impression was Hero's intension. He conceived the moving fire and door in relation to a stationary spectator. The interchange between two and three dimensional spaces, however, makes the spectator conscious of his own movement on the stage. A linear form on an axis is one dimensional. In order to be measured, it has to be compared with another linear section defined by two

points of zero dimension. Similarly, a black silhouette in a square is a two dimensional form which is confined by the one dimensional edges of the square. Finally, a mass in a room is a three dimensional form bounded by the cube that contains it. The cube is defined in terms of two dimensional surfaces. The same analogy can be made about the two protagonists of the device: the fire and the door. The spatial movement of the fire, a measure of its size, is defined by the opening and closing of the door. Similarly, the temple is stretched between two extreme conditions, the opened and the closed.

The visible forms due to the two opposing movements are the quick and irregular shape of the fire and the slow and geometric opening of the doors. The doors are two dimensional objects but upon opening, they reveal the three dimensional inner space of the temple. The doors indeed escape from the two dimensional plane defined by the door frame into the three dimensional space of the temple. At the same time, the door ensemble, as it enters in the three dimensional world, reveals the inner space of the temple whose darkness make it seem flat and two dimensional.

Figures Made to Dance by Fires on an Altar

This device is included in a transparent altar made of glass (see Figure 5). Through the heart of the altar, a tube turning on a pivot, is let down. Smaller tubes lying at right angles to each other and bent at the extremities in opposite directions are attached to the initial tube. A wheel or platform on which dancing figures stand is also fastened to the tube. When the sacrifice is kindled, the air, heating up and

expanding, passes through the central tube while being forced out of the smaller tubes. As it meets the resistance from the sides of the altar, it causes the central tube and the dancing figures to revolve.

This literally kinetic sculpture demonstrates, or rather manifests the concept of the steam engine used for purely artistic means and purposes. It is interesting to note that it will not be until about eighteen centuries later that the steam engine will be invented for modern technological and practical applications. The same holds true for the windmill, whose use Hero demonstrated in his device “Altar Organ Blown by the Agency of a Windmill.”

The World Represented at the Center of the Universe

Hero illustrates his concept of the world as the center of the universe with a transparent globe containing air, in the center of which is a smaller globe representing the earth (see Figure 6). The transparent outer globe consists of two hemispheres of glass, one of which is covered with a bronze plate that has a round hole in the middle. The other hemisphere contains water. A light ball which barely fits through the hole is floating on the water whose level is initially above the bronze plate. Pairing the two transparent hemispheres, a transparent globe containing air and liquid is created. Brumbaugh [2, p. 85] mentions that modern reconstruction of the “Earth in the Center of the Universe” has shown how Hero’s model works.

An outlet tube is added on the lower hemisphere, and as the water is slowly let

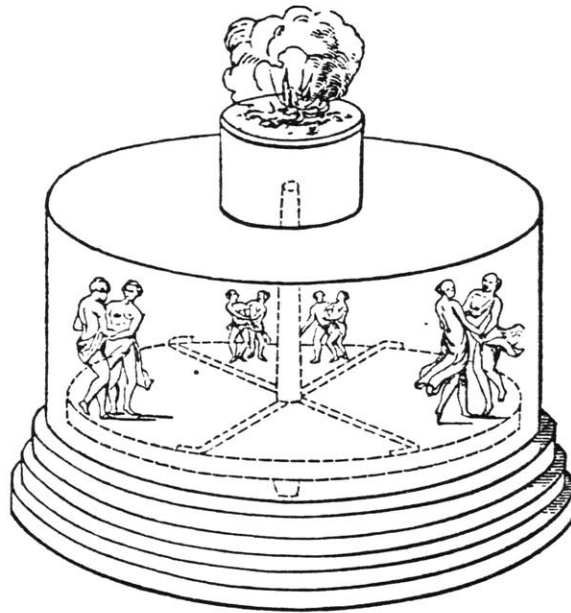


Figure 5: Figures Made to Dance by Fires on an Altar

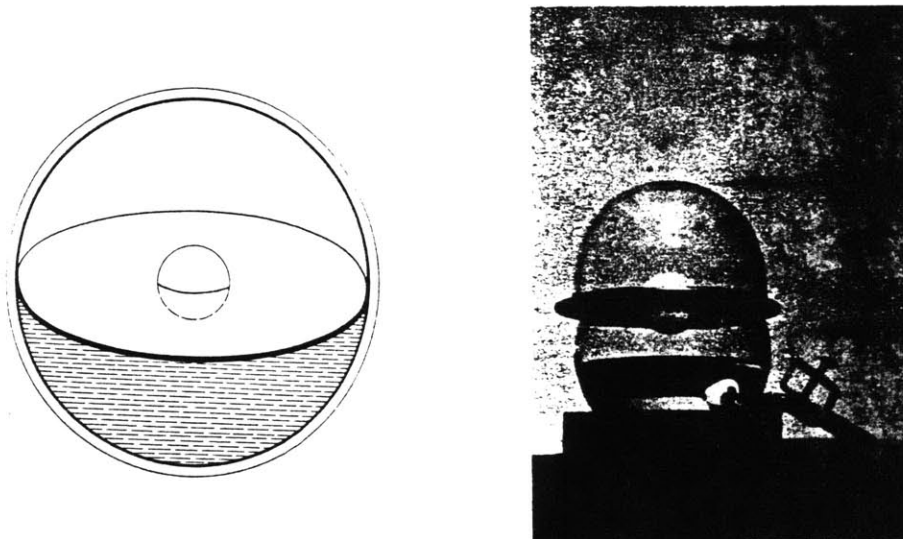


Figure 6: The World Represented at the Center of the Universe

out through the tube, the ball drops into the hole where a water film seals off the top hemisphere. The resulting pressure difference keeps the ball suspended. This device—not a particularly impressive invention or structure—reveals the greatest of intentions: to represent wholeness.

Although Hero uses many rules of physics to the design of the devices, the main principles that guide the operation of the devices are not more than four, as he himself maintains. First comes the principle that when air is heated, the resulting increase in its volume and pressure render it a power source. The second principle is that vacuum is never found in nature but must be produced artificially. The third principle is that if we connect an artificially void space with another containing liquid or gas, the latter will have the tendency to fill the void space. Finally there is the principle of communicating vessels.

On the surface, the initial aim of the devices was to reproduce natural happenings, an aim often encountered in all forms of ancient Greek art (in the case of tragedy mainly after Euripides). In effect, however, this realism is reversed. The devices perform unrealistic, almost magical events (e.g., fire produces water).

The simplicity and the obviousness of the procedure are two ambiguous qualities of the whole work. On the one hand, some of Hero's descriptions may lead us to believe that his intention was to conceal the procedure and emphasize the magical aspect of the event. In addition, the complexity of the structure may seem to have

been geared towards confusing the spectator. On the other hand, the fact that Hero writes down the operational details of the devices proves his willingness to reveal the secrets and expose how the various mechanisms work. Moreover, I maintain that the spectator can perceive the whole procedure both in its entirety as well as in terms of each individual step. Hero uses almost all the natural forces and energy in order to move his devices: the fire, the wind, the sun (e.g., a fountain which trickles by the action of the sun rays), the gravity, the flowing water, the steam. The actions taking place during the operation of the devices reveal the power of these natural elements:

- the lighting of a fire opens a door;
- the wind makes a pipe to sound;
- a jet of steam supports a sphere;
- the water flowing makes a bird whistle.

Cause and result occur at the exact same time and offer themselves for comparison.

The wind blowing becomes as obvious as the sound of the organ.

The unique qualities of Hero's new artform are not to be found in later work on automata. The electricity as power is difficult to be revealed, and the 18th century automata with clock-like mechanisms are too complicated. An application of Hero's *Pneumatica* can be found in Villa-d'Este, a watergarden in Tivoli, Italy. There, an owl fountain designed by Giovanni del Luca and executed by Raffaello Sangallo [18,

p. 100], was based on the device “Birds Made to Sing and Be Silent Alternatively Through Flowing Water.” It was completed in 1580 based on the design of the architect Pierro Ligorio.

Other applications of Hero’s concepts were mainly technological. The principle of the reaction turbine, as it is presented in the device “Steam Engine,” played a major role in the industrial revolution.

Inspired by Hero, Joan Brigham, a contemporary American artist, has made a series of kinetic sculptures named “Aeolopiles” (“Aeolopiles” is the name of Hero’s steam engine device) which use Hero’s principle of the steam engine (compare Figures 2 and 7). The “Aeolopiles” are constructed of glass to allow visibility of the events. The revelation of steam as power and form, is frequently used in the artist’s work. The Greek philosopher Empedocles believed that the universe consists of four elements: earth, water, air, and fire. Hero used the power of these basic elements to set his devices in motion. Many contemporary environmental artists have used the same elements, but rarely have they combined all four of them in an entity. “Earth, air, fire, and water: Elements of Art,” was the title of an exhibition which took place at the Museum of Fine Arts in Boston. The purpose of the exhibition was to present artists who work with mundane substances that are capable of assuming primordial, elementary forms. Some of the artists who participated in the exhibition were Lowry Burgess, Christo, Hans Haake, Allan Kaprow, Dennis Oppenheim, Otto Piene, Richard Serra, Robert Smithson, Alan Sonfist, and Andy Warhol.

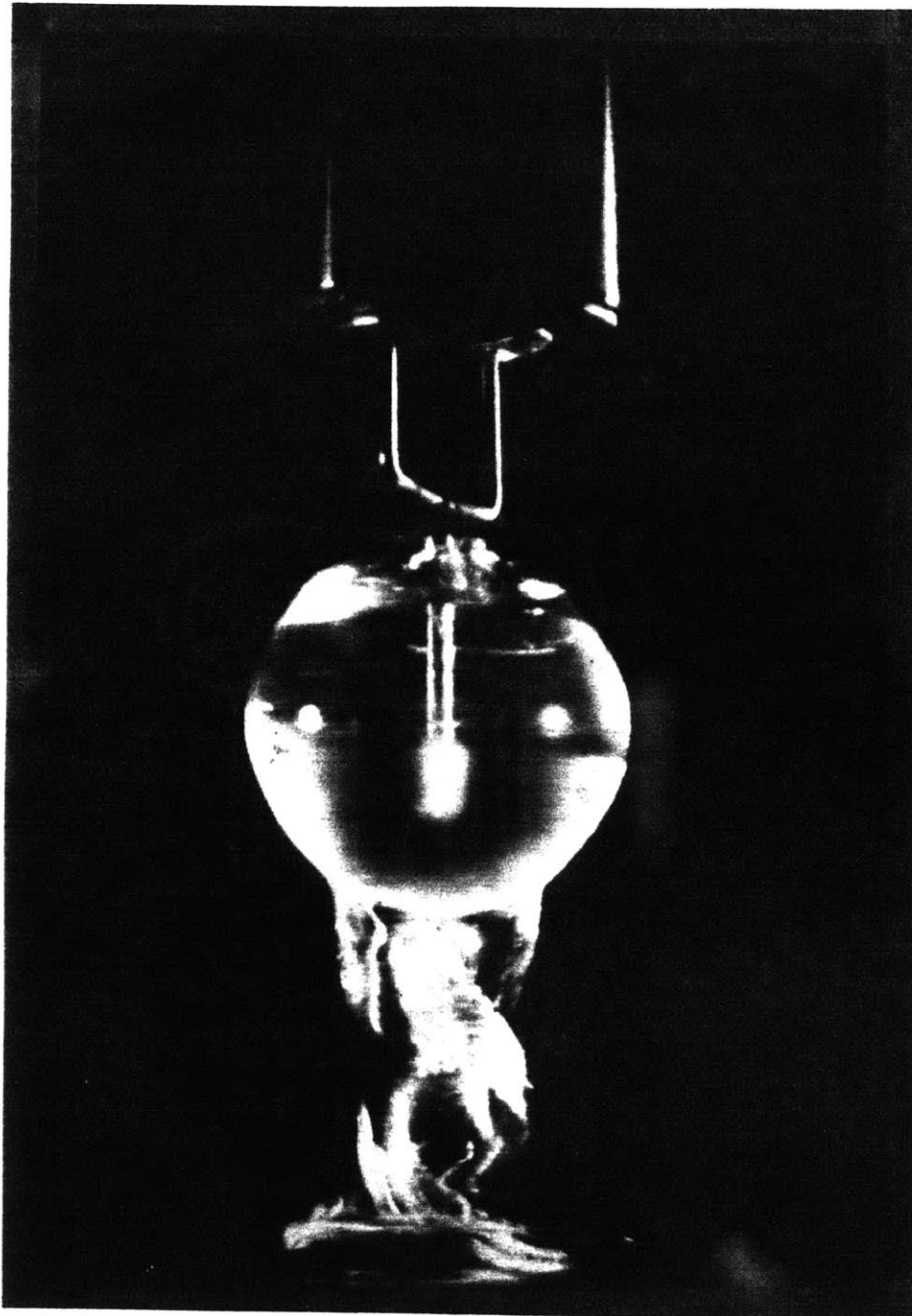


Figure 7: Kinetic Sculpture from Brigham's Series "Aeolopiles"

3 Catoptrica

This section explores the artistic elements in Hero's treatise *Catoptrica* and offers a brief description of the ancient Greek stage designs and mechanisms.

Catoptrica is Hero's treatise on mirrors. In a short introduction, Hero presents some basic rules to be later used in the formulation and description of applications. Hero divides the science of vision into three parts: optics, dioptics, and catoptrics, and claims that Aristotle had written a treatise on optics (e.g., in the *De Anima* or in the *De Sensu*, where the theory of vision is treated. Ancient lists of Aristotle's works also mention one on optics. [3, p. 262]). Hero treats dioptics in his treatise *Dioptra*. The *dioptra* or diopter is an instrument on land surveying or a spying tube.

The two main rules that Hero uses in order to support his applications concerning the catoptrics are 1) sight is directed in a straight line, and 2) the rays are reflected by mirrors at equal angles. He also indicates that the rays are emitted with infinite velocity. The rays as conceived by Hero are not light emitted by a source, such as the sun or fire, but that they start out from our eyes, laying claim to the false belief that our eyes are capable of emitting light.

One of Hero's usual practices is to explore the properties of the subject he examines through several applications. In the introduction of *Catoptrica*, Hero argues that the study of catoptrics is useful not merely in creating diverting spectacles but also for practical purposes, a fact which is reflected in his applications. However, apart from

being practical, these applications in many ways create a new art form and several forms of expression.

Next, I describe three of Hero's applications—call them mirror installations—presented in the *Catoptrica*.

1) “To place a mirror so that one approaching it sees neither his own image nor that of another, but only the image that we select.” Here, Hero describes an installation of mirrors producing the idols of a selected image in a small temple (virtual reality). (see Figure 8). AA is a wall onto which a mirror BG is being inclined. Under the mirror is an image and a statue which has in front of it a mirror ML parallel to BG . The image and the mirror ML are hidden behind a pedestal HN . The viewer is able to see the image on the mirror BG without seeing the actual image. Hero suggests that this whole installation should be in a wooden temple. He also proposes that the image should be illuminated by a secret window. The purpose of the installation is to create a three dimensional image on a two dimensional plane, the mirror. The moving viewer is able to see different views of the image, an effect similar to that of holography. Thus, some of the qualities introduced by the holographic technique already existed in Hero's work. It is possible that the same arrangement was used to present changing images. The images could be installed on a rotating wheel. In the latter case the result is a virtual moving object.

2) Hero suggests that with the placing of two mirrors, BD and AG , an observer will be able to see himself flying (see Figure 9). The two mirrors are both installed above the viewer and inclined at an angle which enables the viewer to see himself upside down and backwards. This simple application based on the properties of mirrors materializes one of the greatest desires of the human being: to stand in the air and fly. This has long been a dream of both artists and engineers (e.g., Leonardo da Vinci and Daedalus).

3) The last mirror installation that Hero discusses is an observatory house (see Figure 10). Sitting on position A in the room, an observer is able to observe position B on the street through a mirror ZX on the ceiling. The image from the street is reflected on the mirror at the area D , and is lead (by equal angles of reflection) to A . In addition, we can install a diopter NX in order to confine our visual subject.

This pathetic observatory is an ancient television. We have a moving image on a two dimensional surface. The image that we see on the mirror on the ceiling is upside down, which may create the illusion that we are upside down instead. The installation is very carefully arranged to select random images from the street.

Catoptrica by the latin name of *De Speculis* was ascribed to Ptolemy, but according to Cohen and Drabkin [3, p. 262] there is independent evidence for the ascription of the *De Speculis* to Hero.

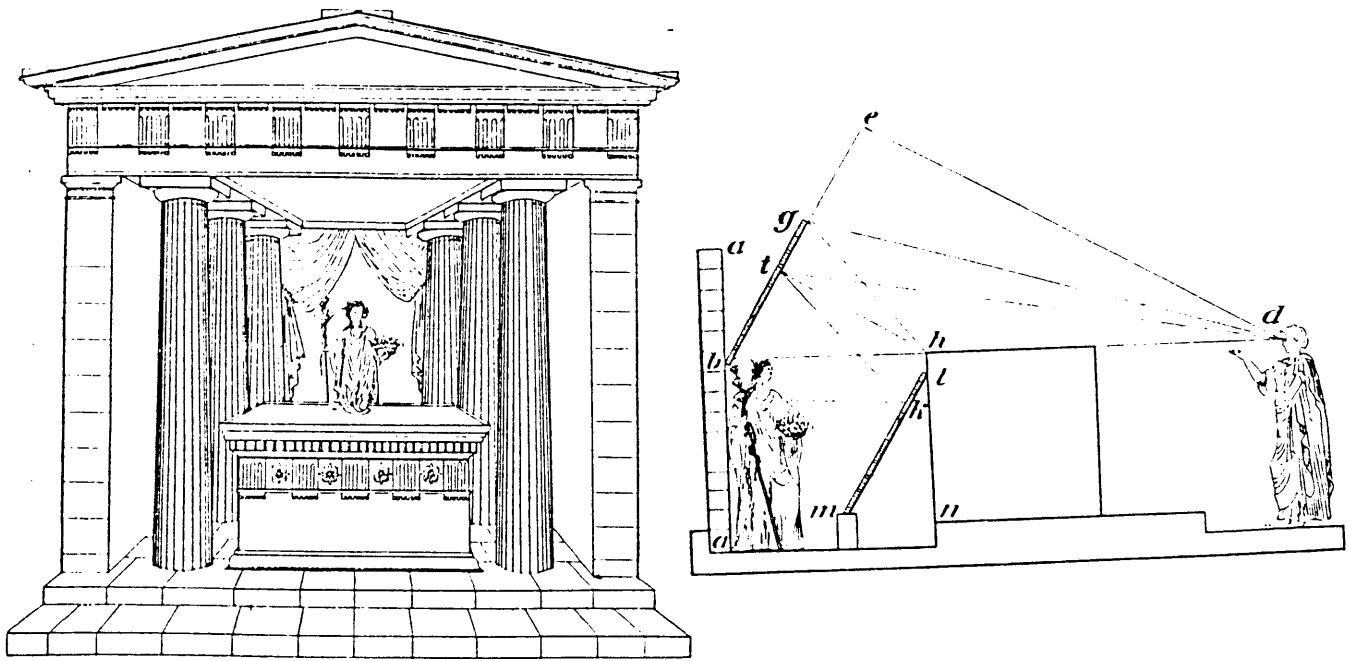


Figure 8: Catoptrics 1

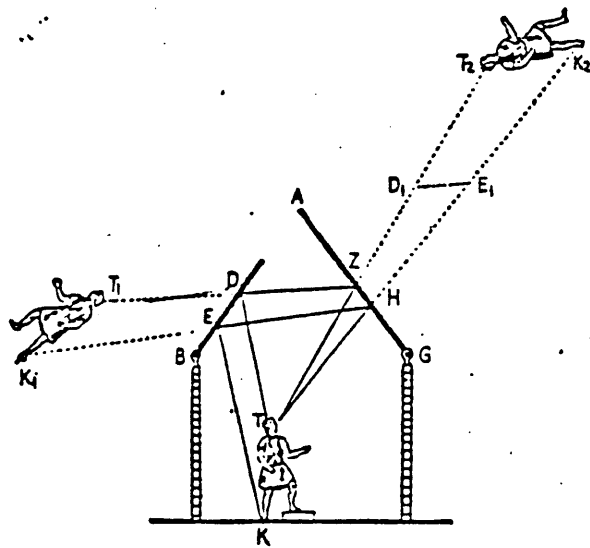


Figure 9: Catoptrics 2

Although there is no proof, it is not unreasonable to suspect that some of the mirror installations were used as stage designs in the ancient Greek theater. For example, the arrangement of mirrors in order to elevate the human figure, could have been used as a *deus ex machina*. The theatrical mirror, one of Hero's installations based on catoprics, consist of a set of mirrors arranged amphitheatrically on a half circle. This way on each mirror appears the image which is at the center of the circle. Also, Hero's installations with concave mirrors allowed the appearance of distorted images. We have no knowledge of other mirror application during Hero's time. Euclides's studies on mirrors, though scientifically valuable, do not provide any lead on their use. According to Cohen and Drabkin [3] however, there is a tradition (in Lucian, Galeh, and others) probably without foundation, that Archimedes set fire to the fleet of Marcellus by using burning mirrors. Strandh [5, p. 28] says about Archimedes's mirrors:

The construction is said to be similar to that of modern sun reflectors, that is to say, it consisted of numerous small polished metal mirrors on a lattice-work structure of parabolic cross-section, rather like the one at the United States Army Research Station at Natick, Massachusetts.

4 Automatopoietica

In his treatise *Automatopoietica* (on making automation), Hero directly refers to a form of art, the automaton theater. The automaton theater blends the art of sculpture (Apollonian element) with the art of music and theater (Dionysiac element). Although not always referred to as *Automatopoietica* (or *Peri Automatopoietikis* in Greek), Hero's work on automata is known under various names (e.g., Wilhelm Schmidt's German translation *Die Automaten theater* [4]).

To date, we have no knowledge of what kind of moving sculptures and images existed before Hero, although there has been a long tradition, beginning with Daedalus, involving moving machines and self-animated objects. Moreover, in *Automatopoietica* there is evidence that Hero's predecessors had written about and experimented with such devices. However, Hero is the earliest source available introducing this art form.

The text of *Automatopoietica* is divided into two parts: "Hypagonta Automata" (moving automata) and "Stata Automata" (standing automata). The difference between the two is that in the *hypagonta* automata, in addition to the motion of the figures-actors, which are three dimensional, the whole stage moves, whereas in the *stata* automata the stage is firm and the only movement is this of two dimensional figures. Next, I discuss the two parts in more detail.

Hypagonta Automata

The only *hypagon* automaton described by Hero appears to be a moving pedestal on which there is a small temple and a number of mobile figures (see Figure 11). Hero suggests that the total height and length of the pedestal should be 92.71 cm and 31 cm respectively. The base is 23 cm high, on which stand four columns 62 cm high, and finally on top of the columns stands a another base 7.71 cm high supporting the figures and the temple. Hero does not mention the dimensions of the figures but supposing that their height is approximately half of the pedestal's height and the pedestal floor is square, the entire construction is 139 cm \times 31 cm \times 31 cm. The pedestal rests on hidden wheels that allow it to move in different directions. On the pedestal stands the temple in which there is a statue of Dionysus with a panther at his feet. Dionysus is holding a *thyrsus* in his one hand and a cup in his other hand. On top of the temple there is a statue of Nike holding a wreath. A circle of Bacchantes and two small altars surround the temple.

This moving automaton theater operates in the following manner. At the sound of cymbals Dionysus turns toward the altar and a fire lights. Nike on the temple roof begins to revolve, and wine flows from the cup of Dionysus. When the god turns again a thunder is heard, and the Bacchantes rotate around the temple while also rotating around themselves. The whole construction may move to different directions. Its motion may be linear, circular, rectangular, or composite. After a certain period of

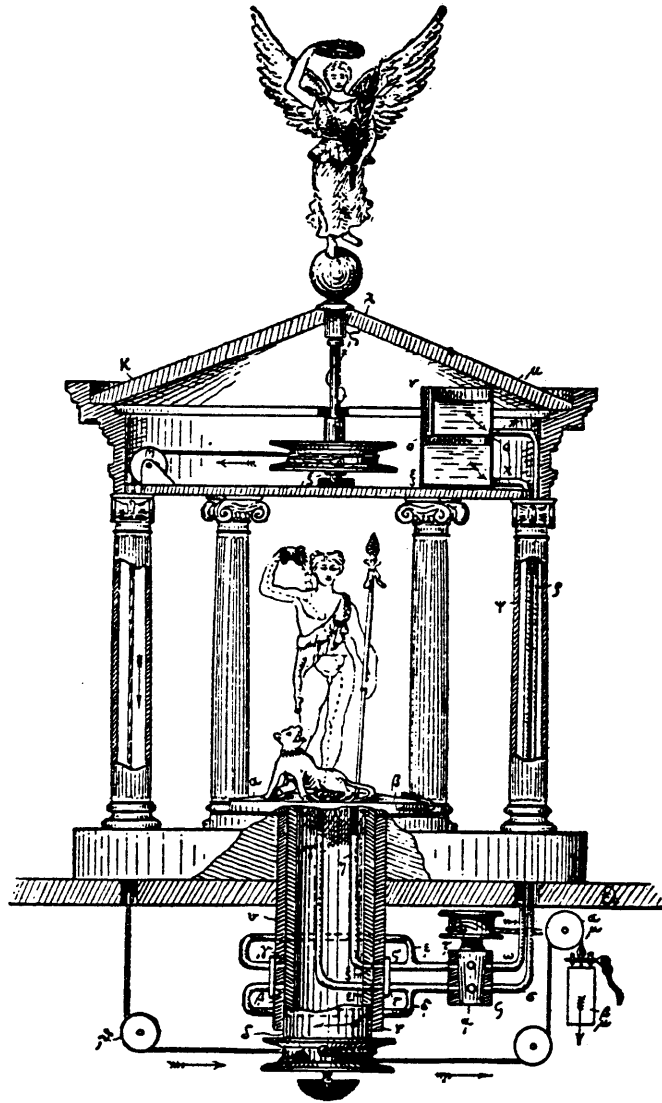


Figure 11: *Hypagon* Automaton

time everything stops.

Hero's purpose is to describe the way that the machine operates. The operating structure driving the automaton is meant to be hidden, but the text reveals the function. The artistic quality of the *hypagonta* automata is both in the end result as a spectacle but also in the underlying structure. I will refer to some of Hero's technical descriptions in order to emphasize the importance of the procedure as an artistic element.

The power source for the most part is dropping weights. The dropping weights result in either a continuous rotating motion (e.g., axle rotation) or discretely unleash some other force (e.g., the flow of wine). Originally, weight operated dolls and theaters had one significant mechanical limitation: the weights dropped too fast. To overcome this problem, Hero proposes to place the weight which is attached to the axle of the pedestal wheels with two pulleys, on top of a sand clock (water clock with sand instead of water). This way, it is the flow of sand through the neck of the sand clock rather than gravity, which dictates the rate at which the weight drops.

Another mechanical detail in Hero's description concerns the way that the wheels are made to rotate with different speeds. In order to create the complex motion of the automaton, Hero suggests a double axle with each part attached to a different weight and one part inserted into the other (see Figure 12). This anticipated the modern automobile differential. Hero's solution for reversing motion is to change the way the rope is wound up around the axle.

What is of great importance in Hero's moving theater is the coexistence of realistic figures-actors and actions with natural forces (e.g., gravity).

Greek drama was born out of the Dionysiac feasts. The Dionysiac pageants, in which originally only Bacchantes participated, developed into a more exotic march with carnivorous animals after Alexander the Great's expedition to Asia. This explains the panther in Hero's automaton.

Stata Automata

While in the *hypogonda* automata the stage is movable and the fond is the open sky (an innovation which to date has not been fully developed) in the *stata* automata the stage is fixed. Hero describes an application of the *stata* automaton theater on the play "Nauplius". This automaton is very close in form to the real theater, and the effort to imitate it is obvious. The play takes place on a stage on which doors that can open and close. Each opening of the doors reveals a different action and a different scenery.

The theme of the play refers to a part of the Trojan War. According to one version of the story, Palamedes, the son of Nauplius, a Greek warrior in the war against Troy, killed Ajax, the Locrian, during a quarrel. Nauplius then appealed to Athena to punish Ajax, and the goddess granting his appeal destroyed Ajax's ship while he was returning to Greece. Another version of the same story is that Ajax raped Cassandra, the Trojan oracle priestess, in Athena's temple during the fall of

Troy. Athena punished him by destroying his ship, but Ajax managed to swim back to the coast safely. As he stood on a rock, shouting that he survived against the will of the gods, Nauplius (the son of or another name of Neptune) crushed the rock and killed him.

Hero arranged the play into five scenes. The first scene consists of twelve figures in three rows which represent the Greeks who are repairing their ships. One is sawing, others are hammering, all under the sound of actual working. After a set time, the doors close and when they open again, a ship is seen launched into the sea. This is the second scene. The third scene depicts sailing ships and swimming dolphins in front of a sea and sky painted background. In the next scene Ajax is holding a torch, while fire and smoke is everywhere. Athena is standing on the top of the stage. The doors close and open one more time revealing the last scene. There, as Ajax is swimming, Athena sends a lightning bolt on him and leaves. The figure of Ajax disappears, and the doors close for the last time.

The whole performance is operated mechanically. The openings and the closings of the doors, the movements and the sounds are all predetermined by Hero. In order to get the effect of the jumping dolphins, Hero suggests attaching dolphin figures on a wheel which is half-dug into the stage (see Figure 13). As the wheel turns by an untying rope connected to a dropping weight, the dolphins appear and disappear.

Another mechanism described by Hero is that of the hammering figure (see Figure 14). There, the repetitive raising and falling of a lever guided by a peg-and-lever

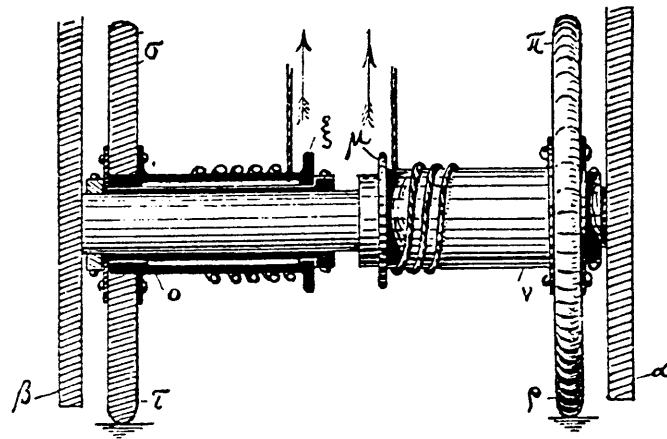


Figure 12: Wheel Axle

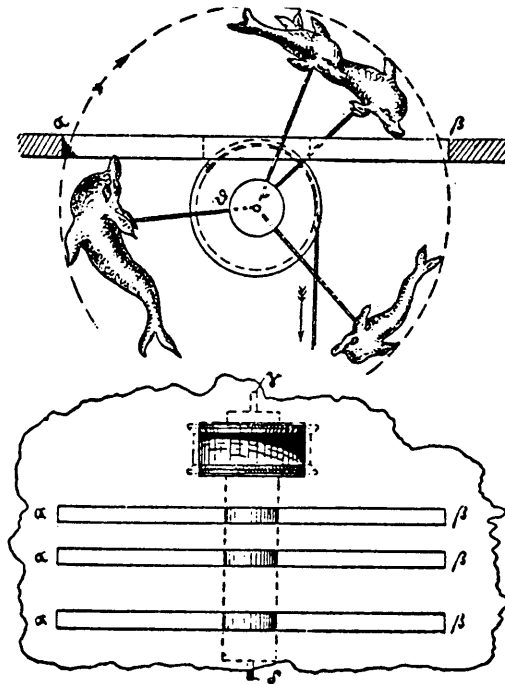


Figure 13: Dolphins

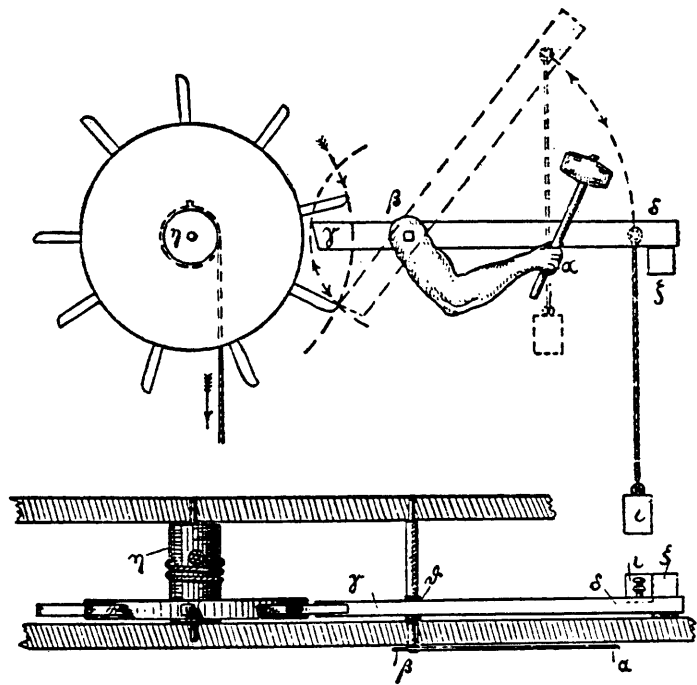


Figure 14: Hammering Figure.

mechanism appears as the arm of the hammering figure.

Figure 15 shows the mechanism for the lighting effect. The idea here is that a panel depicting a lightning drops, and at the same time, the background scenery for the next scene is unrolled. The sound effect of the thunder is created by the fall of metal balls on a drum.

Most of the figures are two dimensional and Hero pays great attention to the painted background in the back of the stage. These moving, two dimensional figures compose a kinetic painting, a simple form of cinematography. Similarly, the *hypagonta* automata are more like kinetic sculptures.

In the Hellenistic theater the actors perform more on the *proscenion*, the raised stage in the back of the theater, and less on the orchestra. The reason for this, according to Bieber [8, p. 108], is to make these individual figures visible to the audience with relief like precision. The same two dimensional stage that pursues the portayal of the individual characters in the realistic Greek theater exist in Hero's *stata* automata.

Hero is not only concerned with the effect that motion may have on an object but also with the form actually possessed by the object in motion. Both the *stata* and the *hypagonta* automata go from a state of rest to a state of motion only through the intervention of an outside force. But, whereas in "Nauplius" Hero creates the illusion that the automaton possesses an inner source of motion, in the automaton featuring Dionysus, he actually recreates the essential aspects of an object that can generate its

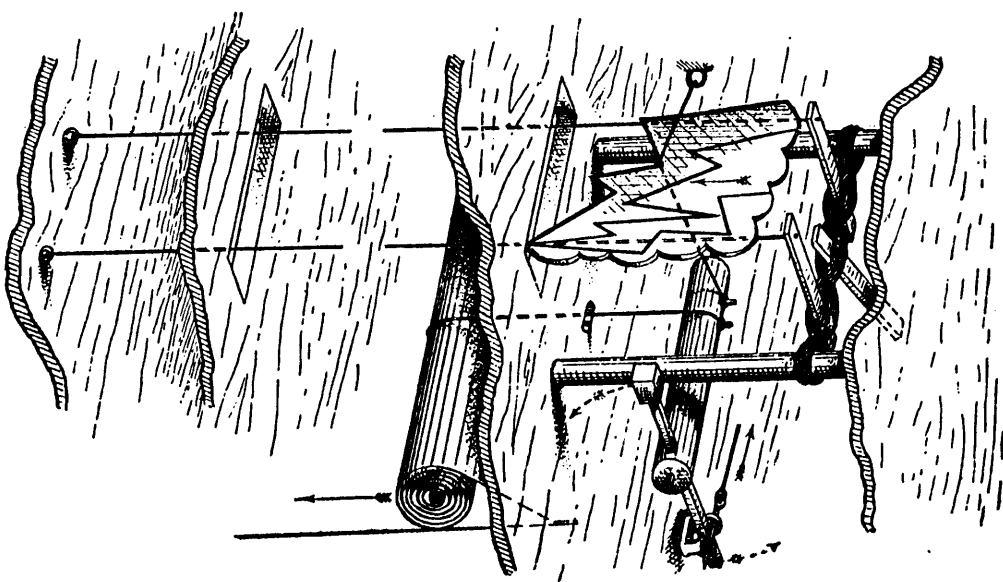


Figure 15: Lightning Machine

own motion from within itself. This inferiority of the Nauplius automaton compared to the Dionysus automaton is compensated for by its motion in time. Thus, whereas the Nauplius automaton give a story telling experience to the spectator through its sequence of scenes, the Dionysus automaton has no particular story to tell.

5 Hero's Descendants

This section discusses the work of artists-engineers that is directly connected to Hero's proposals and makes some points about the contemporary automaton theater.

We know very few things about Hero's predecessors. Daedalus, the Athenian master of all crafts (in ancient Greek the word for craft, *techne*, also meant art), built statues that had to be kept chained in order not to run away ([2, p. 23]). Even the eyes of the statues gave the impression that they could actually see (they probably moved).

Archytas of Tarantum also is said to have invented a bird toy which was able to fly although the bird was probably some sort of kite. Nevertheless, Hero's texts are the only direct sources on automata. His mirror installations and his automata were probably in frequent use in Alexandria, but it was not until the 16th century A.D. that similar applications was constructed again.

Leonardo da Vinci, who often sought to combine technological inventions with art, was inspired by Hero in some of his mechanical devices. For example, Leonardo's series of devices meant to measure surface distances, is an improved version of Hero's invention, the odometer. Of great importance are also Leonardo's drawings describing stage designs (see Figure 16). Leonardo designed the stage for Bernardo Bellincioni's play "Paridiso". The scenery of "Paradiso" embodies Hero's ideas by combining mechanical ingenuity with the theatrical form of expression. The performance of this

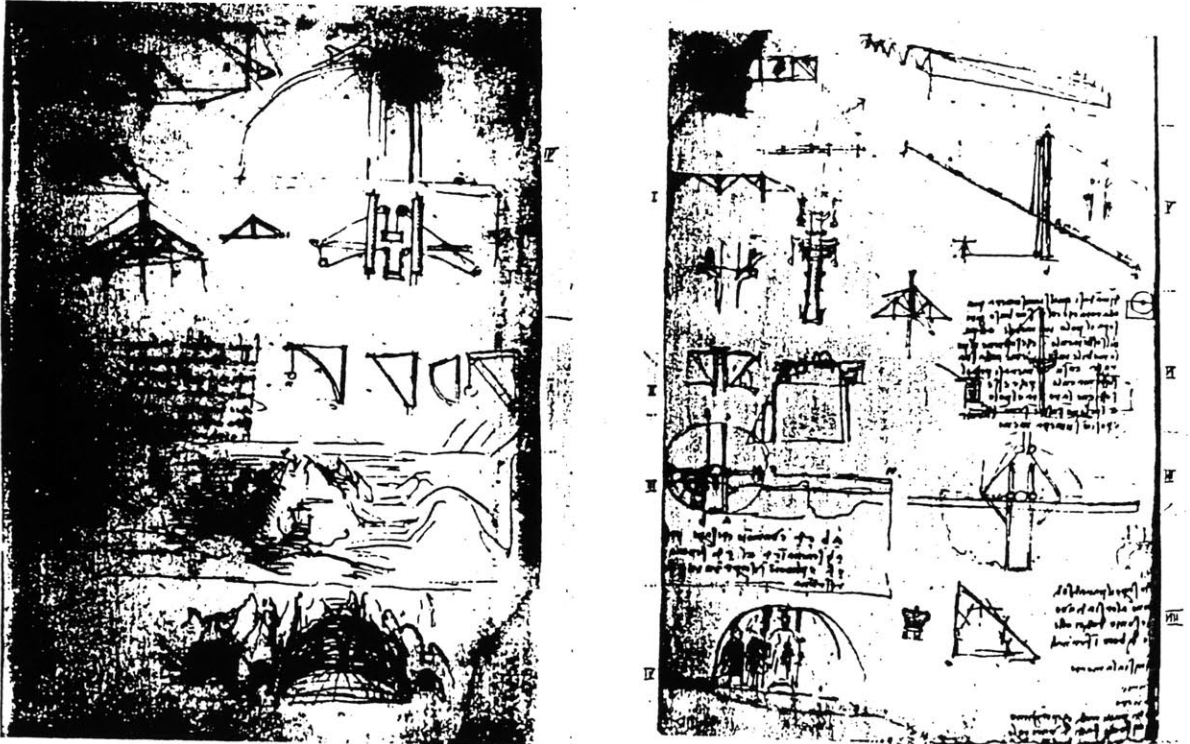


Figure 16: Leonardo Da Vinci's Stage Design

play was connected to the marriage of the Duke of Milan, Giangaleazzo Sforza, to Isabelle of Aragon on January 13, 1490. The main stage design was a mountain which opened to reveal seven hung rotating planets against a background of a sky with stars and the twelve signs of the zodiac lit from behind. The description of the mechanism to open and close the mountain is contained in two of Leonardo's note pages. As Steinitz [25, p. 325] put it, Leonardo, always interested in the movement and animation of the inanimate, built the first revolving stage in Europe.

Several artists-engineers explored the interaction between moving sculptures and machinery in various theatrical machines. Evidence of such machines can be found in the *Encyclopedie* edited by Diderot and d'Alembert in Paris between 1751 and 1772. One of the stage machines in *Encyclopedie* describes a scaled drum, which operating as a pulley, raises or lowers a series of clouds that are attached to it with cords. This stage design is installed to prepare for the arrival of a chariot coming down from the sky through the clouds (see Figure 17).

The intense interest for the functional machinery that followed the Renaissance led to the construction of many devices. Some of them, though designed without any direct artistic intention, are visually interesting. One of these machines is the "Collapsible and Movable Bridge" (see Figure 18). The complicated operating system of this mechanical bridge though purely functional, also works as an environmental sculpture.

The technological progress that occurred during the Renaissance opened the path

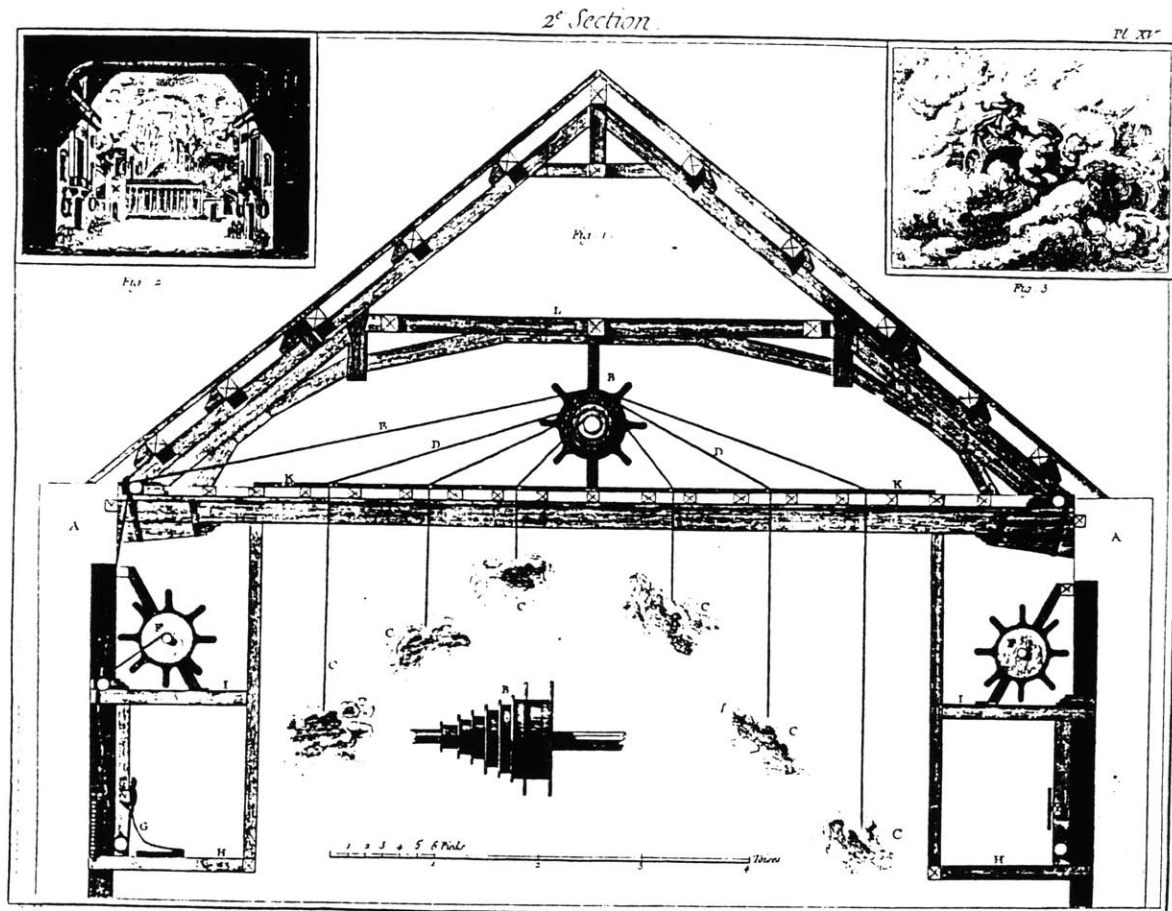


Figure 17: Stage Machine from *Encyclopedie*



Figure 18: Collapsible and Movable Bridge

to the construction of automata with extremely effective ways of operation. In the beginning of the 17th century Salomon de Causs built a number of moving figures in the garden of the Heidelberg palace. The movable figures were placed in caves and were operated by water wheels and a series of pulleys and ropes (see Figure 19). Salomon de Causs was inspired by Hero and describes many of Hero's automata in his book *About Violent Forces. A Description of Some Useful and Amusing Devices*, first published in 1615.

The continuing development of complicated, minute mechanisms (mainly systems of gears) that produced the first watch pushed forward the research on automation. However, the increasingly complicated structures which relied less and less on natural sources made the automata less direct and revealing than before. Hero's automata are artistically more interesting than their 17th or 18th century counterparts, since their objective was not merely to imitate the physical process. An example of the abusive copy of nature is the Vaucanson's famous duck which with a mechanism of more than a thousand parts ate, digested, and excreted the remains (see Figure 20).

Progress distanced technology from everyday life and art, so artists had to invent a new way to approach the automaton theater in the 20th century.

6 The Contemporary Automaton Theater

Many artists of our century have worked along Hero's lines. In this chapter I present some examples of work related to that of Hero, and in addition I express some personal views on the mechanical stage. The artists whose work is related to the automaton theater are mainly of two categories: those who work on the theater and on the stage in general and those who construct kinetic sculpture.

Oskar Schlemmer and the theater of the Bauhaus is the most important example of the first category. Schlemmer developed the Bauhaus stage shop after he joined it in 1921. He interpreted the stage as an extension of the human body and movement. Schlemmer claims that theater is the most heterogeneous assortment of creative elements. The stage should reflect life and be the image of our time. Schlemmer's theater is composed of the abstract-formal, the static, the dynamic, the monumental, the mechanical, but also of that which can not be mechanized. Laszlo Moholy-Nagy's "Light-Space Modulator," originally designed to produce light effects for a movie, is a contemporary kinetic stage design. Also related to the Bauhaus, Heinz Loew designed the model for the "Mechanical Stage," a stage in which the interaction of various movable objects was controlled mechanically (see Figure 21). The stage set for the ballet "Le Chatte," created by Naum Gabo and Antoine Pevsner in 1926, is another example of a kinetic stage design. In our century electricity has been the primary power source for kinetic work. Although many artists involved in kinetic

sculpture have incorporated Hero's ideas of movement and automation, they failed to exploit natural forces.

The kinetic sculptures of the Swiss artist Jean Tinguely are driven mainly by electricity. Tinguely's work is an example of the second category of artists that work mainly as sculptors, but he has also attempted to project his work on the stage. In 1953 Tinguely with Daniel Spoerri worked on project "Auto-Theater," in an attempt to bring action to the stage with or without actors. In 1966 Tinguely also made the stage design for the ballet "In Praise of Folly" choreographed by Roland Petit (see Figure 22).

There, a dancer pedalling a bicycle-like mechanism powered the machine. The whole construction, lit from behind, was projected on a white cloth, creating a shadow-play. Finally, the series of fountains by Tinguely (Brunnen 1975-77 and Stravinsky Fountain in collaboration with Nikki de Saint Phalle 1983) borrow many elements from Hero's *Pneumatica*, using water and moving mechanical parts.

Hans Haacke's "Sphere in Oblique Air-Jet," (1967) consists of a balloon stably balanced on columns of air. This entire kinetic/non-kinetic sculpture (the dynamically moving and barely visible air supports a static sphere) directly derives from Hero's device "A Jet of Steam Supporting a Sphere," where a light ball is suspended on a jet of steam coming out of a cauldron (see Figure 23).

Hero's devices resemble with simple computers. Like computers, they perform a specific set of commands, the only difference being that they cannot be reprogrammed

to perform a different set of tasks. An artistic approach to computer science would be one that reveals the existence of these commands and the constraints that the programmer imposes on the program. For example, a program that I wrote with A. Pangas in Greece draws random lines in random angles blooming a tree. Running the program consecutive times, one can reveal these constraints (see Figure 24).

One can further provide aesthetic restrictions to produce a variety of results. Consider for example a constraint where the area of a black surface enclosed in a white surface is such that their ratio is given by the *golden section* ratio. In addition, holography and holographic television embody the same principles that are present in Hero's work, especially the *Catoptrica*.

I find, however that it is the theatrical aspect in Hero's work, the aspect of direct communication, which purifies the automation and leads to art. In this spirit, my project, an automaton stage is based on the following ideas.

- The viewer, the reader, or the auditor should stand against the work of art.
- The work of art should be a self-contained unit.
- Technology should be used in a way to distinguish itself from man.
- Hero reveals natural powers through his devices. The revelation of electricity is a silent continuous emission.
- My stage is a still electronic screen which faces and illuminates the viewer.

Based on the above points, my project takes the following form. A half-transparent / half-translucent screen 8 ft × 26 ft is lit from behind. The light penetrates the screen, passes the viewer, and falls on a nearby wall. The light sources are slide projectors and lasers. The lasers illuminate holographic masters to project their images on the screen. Figures 25 and 26 depict some of the initial stages of the project. The light automaton changes constantly as projections from several sources using various media changes—and it changes through the constant movement of the spectator—and the resulting light, sound, and shadow play on surrounding surfaces and surfaces of “screen sculptures.”

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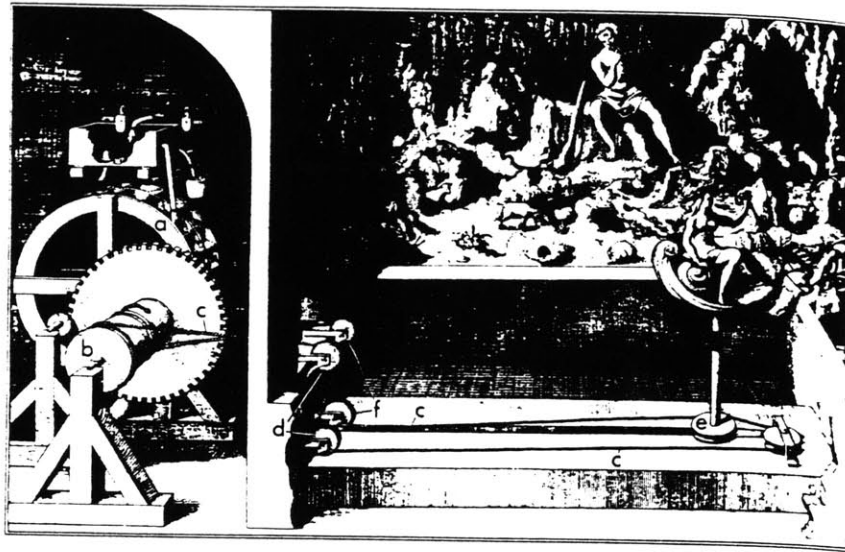


Figure 19: Heidelberg palace

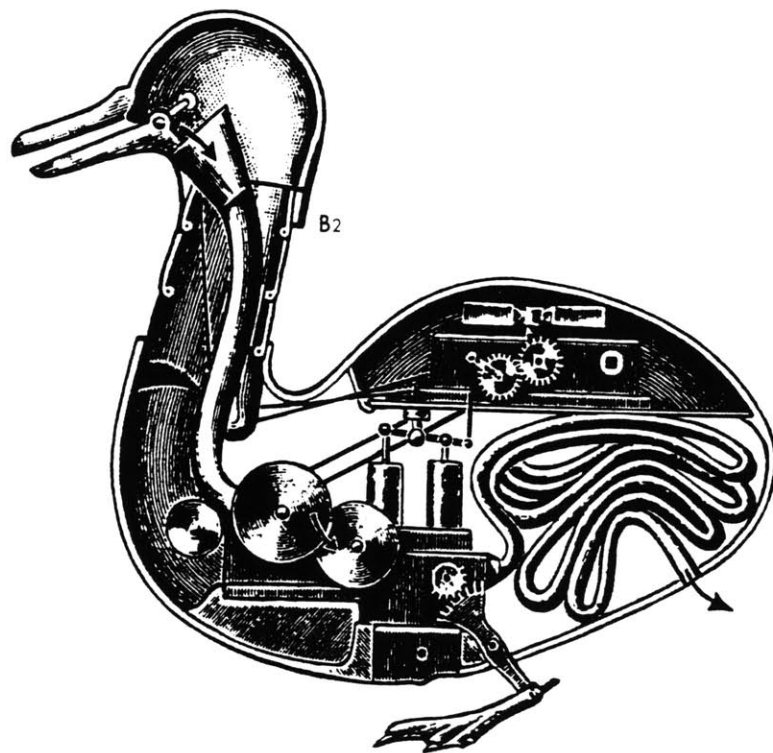


Figure 20: Vaucanson's Duck

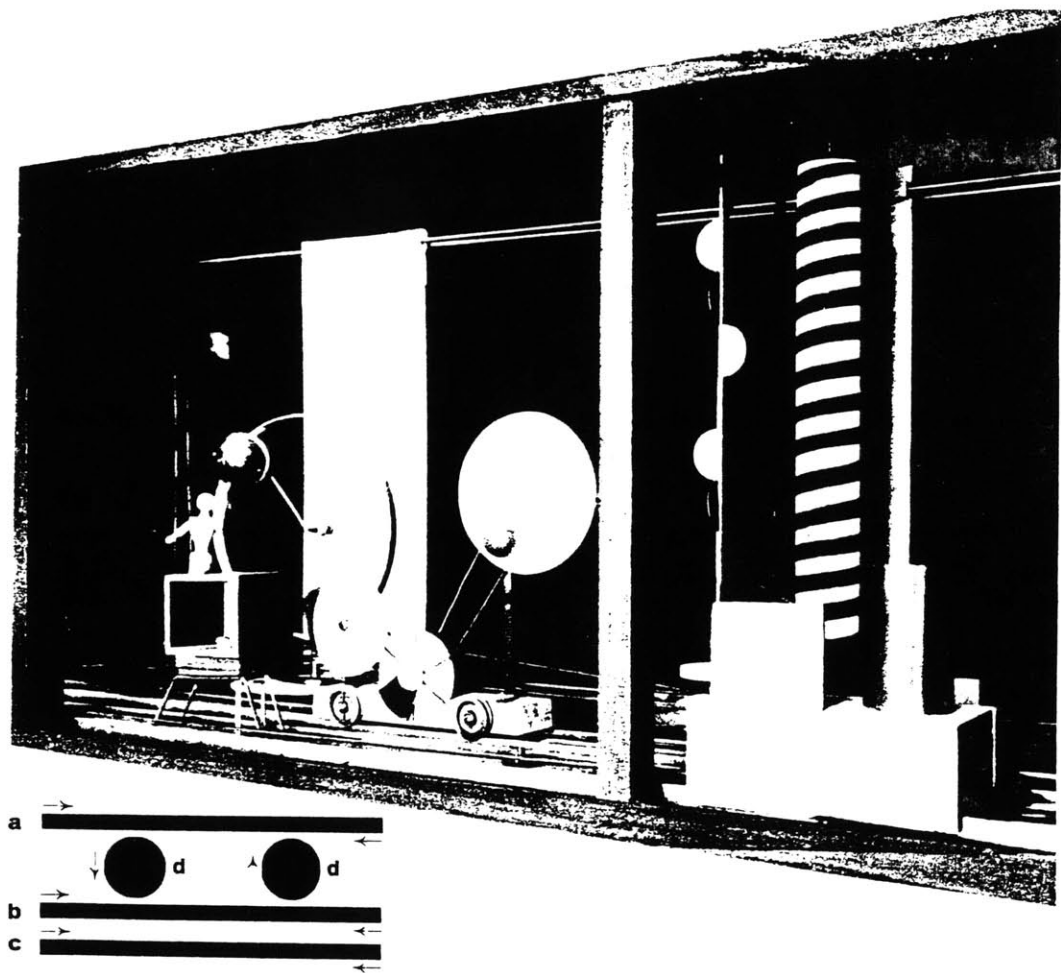


Figure 21: Mechanical Stage

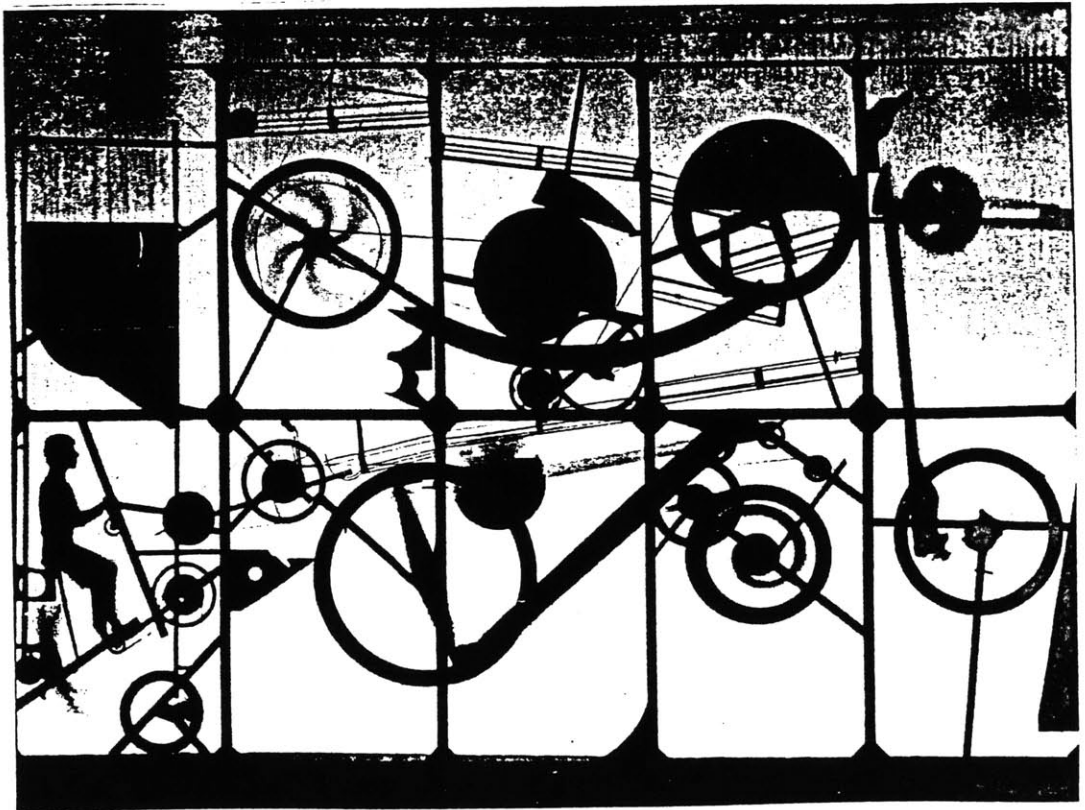


Figure 22: Tinguely's Stage Design



Figure 23: Jet of Steam Supporting Sphere



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Figure 24: Randomly Blooming Tree

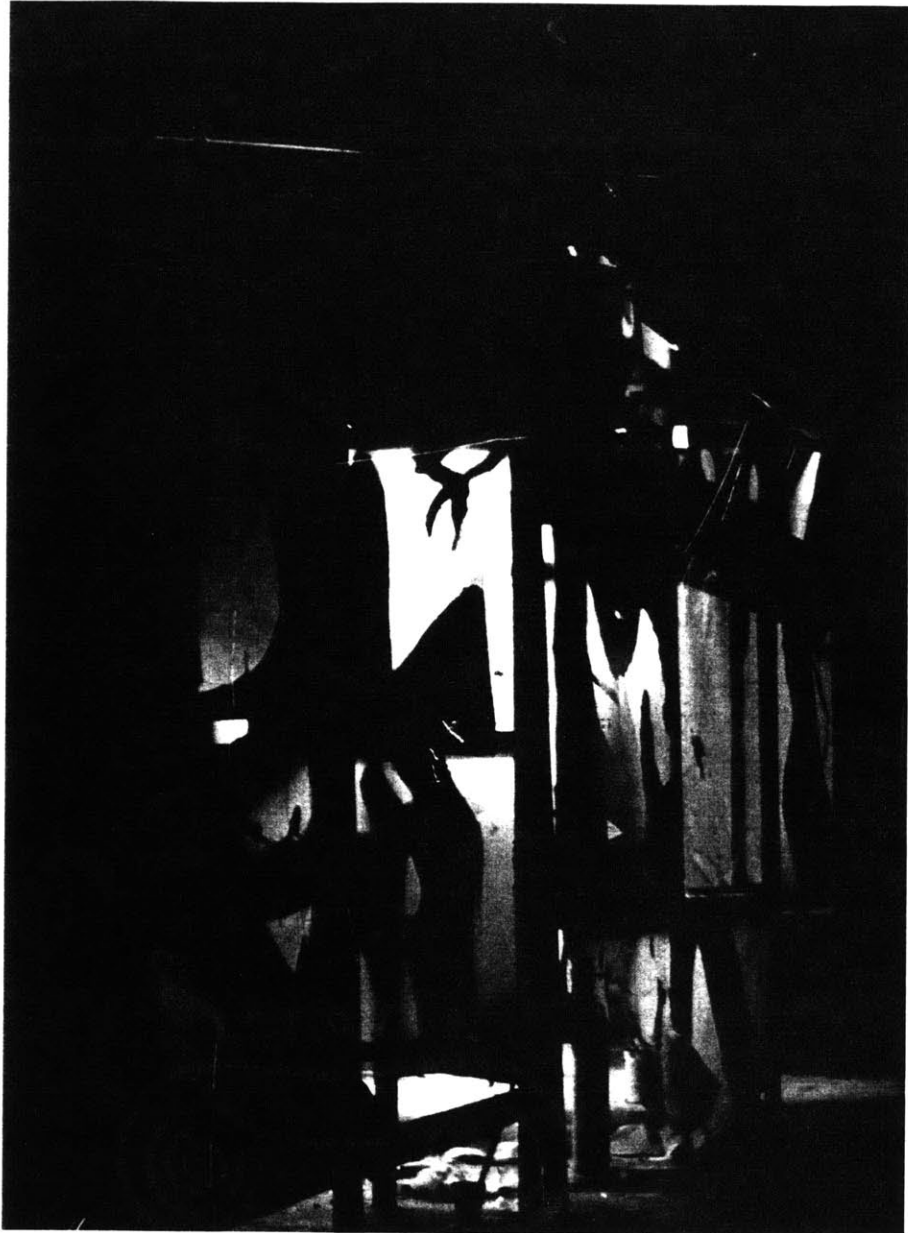


Figure 25: Screens



Figure 26: Projections