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## ARCHITECTURE, AUTOMATA, AND ARTIFICIAL MEMORY

**ABSTRACT:** Artificial memory is an essential precondition for automata, one with a rich collection of conceptual and technical precedents. This paper frames artificial memory as both a technical media and a mode of spatial experiment, arguing that the intersection of mechanical and spatial invention catalyzed early experiments in automaton memory. More specifically, seventeenth century architects played pivotal and surprising roles in the development of artificial “memory architectures” through their work in the creation of large-scale reprogrammable musical automata. In these early, perhaps original, forms of automata memory, we see not only the provocative roots of autonomous machines but also a powerful and expansive view of the architect as transdisciplinary inventor.

**KEYWORDS:** automata, architecture, memory, organs, Salomon de Caus

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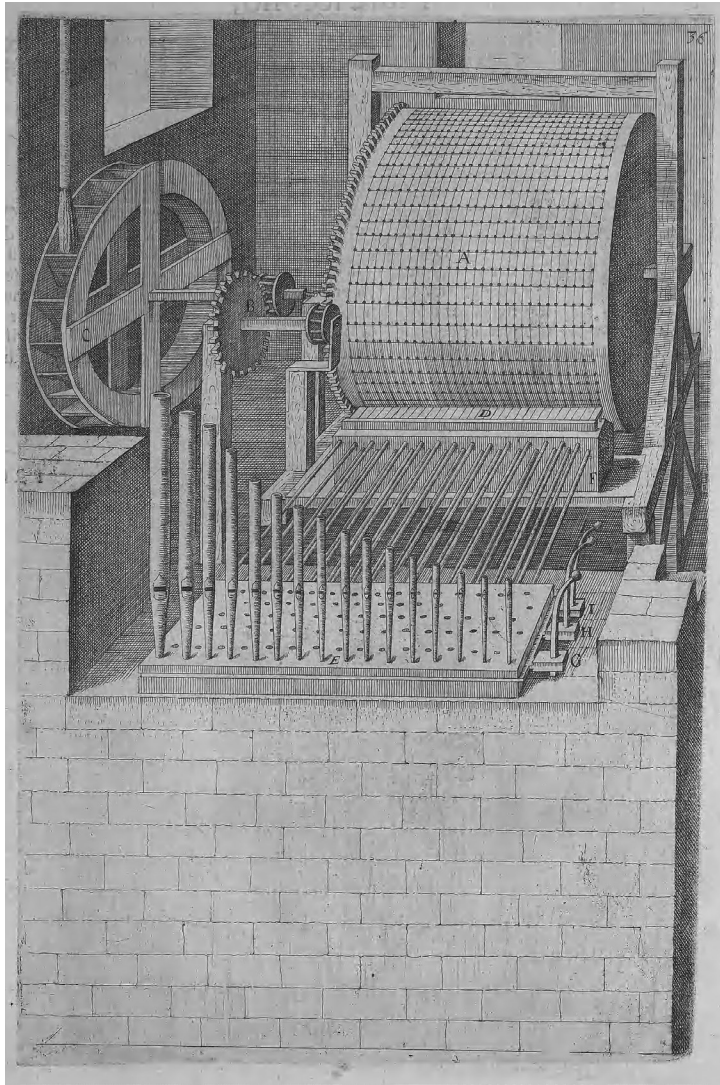


Figure 1. Salomon de Caus's Problem XXVIII in his First Book is "Machine by which one would make the sound of playing the Organ, by means of water" [*Machine par laquelle l'on fera sonner un jeu d'Orgues par le moyen de l'eau*]. Source: S. de Caus, *Les Raisons des Forces Mouvantes, Avec Diverse Machines t'ant Utiles que Plaisantes*, Jan Norton, Frankfurt, 1615.

When did machines begin to remember? When did they gain a language of instruction, inscrutable to human eyes, and the power to execute instructions, unbound to human hands? More than poetic musings, these questions hunt for the moment when machines, through memory, subtly shifted from inert objects towards lively and even intelligent beings. Without memory, an automaton is condemned to a Sisyphean repetition that is only a meager shadow of action. Memory—and particularly the potential of a machine to be reconfigurable, reprogrammable, and adaptive—is an essential foundation for more advanced automation such as autonomous robotics and artificial intelligence. When did memory become mechanized?

Today, “memory architecture” often evokes the chip-scale technical apparatus for storing digital data and code for computational processing. For architects, artificial memory comprises an array of technologies and media that shape creative practice through their modulation of recorded data and information. Yet architects have also long understood memory as amenable to its own artifice spatial typologies and experiments—libraries, museums, memory palaces, memory theatres, and beyond—that spatialize organizational regimes of memory. Artificial memory thus implicates a set of technologies on the one hand and a set of spaces on the other.

In certain extraordinary circumstances, artificial memory can be both a technology and a space simultaneously. Among the earliest formats of machine mnemotechnology were just such hybrids: architectural-scale mechanical contrivances that orchestrated the technological behavior of sophisticated automata. More specifically, I argue that a particular seventeenth century programmable automaton, the water organ, was one of the earliest instances of reconfigurable machine memory, and that its creation drew on the fluid and expansive disciplinarity of seventeenth century architecture. As they advanced in Renaissance Europe, musical automata were a locus of surprising encounters between a mathematically-inclined architects and experimental automation technologies. The scope of renaissance architecture that encompassed hydraulic proto-engineering on the one hand and an intimate understanding of geometry on the other allowed architects to contribute substantial innovations to this field. Moreover, the mathematical conventions of notation, knowledge organization, and memory offered a formative bridge between architecture and automation in the high Renaissance. Thus, architects at this pivotal moment drew on an unusual constellation of skills spanning

spatial design, mathematics, and engineering to make machine memory by architectonic means.

The memory of these programmable automata was arguably one of the first media intended to be read by a non-human entity. Machine readability requires the encoding of information in a format optimized for machinic processing, instead of human legibility. This encapsulation of instructions or protocols in machine-readable media make sophisticated processes portable and recombinant.<sup>1</sup> In effect, this encoding establishes a peculiar kind of language that allows the encoded content to vary and yet remain machine readable. The origin of machine memory is thus intimately tied to how instructions and protocols are embodied in machine readable media.

Far from an idiosyncratic historical curiosity, the question of how memory is both encoded and spatialized is foundational to concepts of machine intelligence. A reconstruction of the origins of machine memory can reveal insights into the singular role of memory in the construction of intelligent machines, as well as the peculiar role that architects have played in imagining artificial and automatic memory.

### MEMORY TECHNOLOGIES, MEMORY SPACES

Architects have tended to frame artificial memory either as a technological medium or as a particular kind of experiential space. On the one hand, as technologies of recording and organizing information—that is, of creating artificial memory—have advanced, the aims and practices of human remembering have transformed. Historian Ann Blair has suggested that “what we take to be human capacities, say, of memory and recollection, change over time under the impact both of cultural expectations and the technologies with which we operate.”<sup>2</sup> Technologies of memory shape practices of memory. In an architectural context, historians and theorists point to the essential ways in which the media of recording and artificial memory—from writing to digitization—have augmented and altered the practice of design. In the modern period, Mario Carpo cites Leon Battista Alberti’s use of recording formats of texts and tables as a way of “preserve the fidelity to the original of the copies of images he valued, used,

<sup>1</sup> A. Witt, *Formulations: Architecture, Mathematics, Culture*, MIT Press, Cambridge, Mass., 2022.

<sup>2</sup> A. Blair, *Too Much to Know: Managing Scholarly Information Before the Modern Age*, Yale University Press, New Haven, 2010, p. 3.

and needed.”<sup>3</sup> The Albertian role of artificial memory was to ensure exact reproducibility and endless identity, in effect to automate repetition.

More recently, advanced technical media of memory have allowed machines themselves to remember, raising the question of the relationship between human and machine memory. For a machine to remember is really for it to scan a recorded memory that is machine readable. Looking to the dawn of the computational age, Zeynep Çelik Alexander observes that “technologists working on the problem of scanning took for granted that the storage of sensory stimuli in the human nervous system and information in a machine were analogous”—that human and machine memory had some fundamental parallels.<sup>4</sup> Yet the isomorphism of human and machine memory is not a given, and in fact early experiments would venture forms of machine memory quite different from our own.

Beyond the array of technologies it may implicate, the concept of artificial memory evokes for the architect ways in which regimes of memory might become spatial. An early example of such spatial memory regimes was Giulio Camillo’s theater of memory, an imagined space in which to behold the totality of human knowledge. Articulated in his posthumously published 1550 work *L’idea del teatro*, Camillo proposed a curious room with a tiered system of seven semi-circular racks on which were arrayed dense sequences of discrete images each evoking a distinct domain of knowledge. As historian Lu Beery Wenneker observed, “the images should be striking and out of the ordinary, extremely beautiful or extremely ugly, gory or comic, but above all, distinctive.”<sup>5</sup> These images comprised a kind of panoramic collage of knowledge or memory, apprehended in spatial terms. The theatre was an atlas of idea-images unfurled onto the walls of an immersive space.

Architects have long mused on the architecturalization of Camillo’s curious speculation and adjacent memory spaces. Daniel Libeskind, for instance, attempted to construct a machine that implemented *L’idea del teatro*, a project for which Camillo himself left no drawings. For the 1985 Venice Biennale, Libeskind presented a triad of writing, reading, and memory machines that he called “Three Lessons in Architecture”

<sup>3</sup> M. Carpo, *The Alphabet and the Algorithm*, MIT Press, Cambridge, 2011, p. 54.

<sup>4</sup> J. May, Z. Ç. Alexander, *Design Technics: Archaeologies of Architectural Practice*, University of Minnesota Press, Minneapolis, 2020.

<sup>5</sup> L. Beery Wenneker, *An Examination of L’idea del teatro of Giulio Camillo, Including an Annotated Translation, with Special Attention to his influence on Emblem Literature and Iconography*, PhD Diss., University of Pittsburgh, 1970, p. 4.

produced under his direction at the Cranbrook Academy of Art. The memory machine reframes Camillo's theatre as a room-scale wooden frame with a vertiginous menagerie of documents, images, and objects suspended above and around the occupant, animated by an intricate set of pulleys, wheels, and gears. The effect is that of a scaffolded and deconstructed music box. A hybrid machine-space-furniture, the Memory Machine articulates mechanism as a kind of tectonic, though Libeskind argues "the subversive element of mechanics (Teatro Farnese versus Teatro Olimpico) enters only in those places where memory has succeeded in retaining its surrogate authority."<sup>6</sup>

Libeskind's project show that what appears *prima facie* as a dichotomous distinction between memory technologies and memory spaces actually invites the creation of hybrid architectural memory machines. In fact, it is this possibility of a memory machine at an architectural scale that suggests a dialog between architectural and computational modes of creation, with the notion of artificial memory a generative catalyst.

#### PHILOSOPHIES OF ARTIFICIAL MEMORY

Beyond their architectural implications, philosophical investigations into memory have attended primarily to the status and functions of human memory, with occasional exotic forays into the space of animal consciousness. Indeed, to the extent artificial memory is considered philosophically, it has often been seen primarily in ambivalent or even malign relation to human memory. As an apparatus for the externalization of individual and collective human memory, artificial memory can be accused, perversely, of being a catalyst for human forgetting. French philosopher Bernard Stiegler, one of the foremost theorists of technological memory, argued this position to a certain extent: that "technicization is what produces loss of memory" through this process of externalization.<sup>7</sup> For Stiegler this process of externalizing memory, as well as a range of other biological functions, is what most authentically characterizes the fundamental trajectory of human history.<sup>8</sup> As Stiegler says, it is a trajectory of reciprocal creation, of "The technical inventing the human, the human

<sup>6</sup> D. Libeskind, *The Space of Encounter*, Universe, New York 2001, p. 180.

<sup>7</sup> B. Stiegler, *Technics and Time, 1: The Fault of Epimetheus*, trans. Richard Beardsworth and George Collins, Stanford: Stanford University Press, 1998, p. 3.

<sup>8</sup> B. Roberts, "Cinema as mnemotechnics," *Angelaki: Journal of Theoretical Humanities*, 11, 1, 2006, p. 56.

inventing the technical.”<sup>9</sup> Nevertheless, even for Stiegler, machine memory is to be understood primarily in relation to human capacities and, ultimately, existence.

To properly understand the role of machine memory in the longer trajectory of artificial intelligence, we must attend to machine memory not primarily in relation to human faculties but rather as an independent dimension of machine autonomy. In that respect, the distinctions from the philosophical analysis of human memory prove surprisingly rich when transposed to our understanding of machine memory.

In their influential 1966 paper “Remembering,” philosophers C. B. Martin and Max Deutscher propose a particularly useful tripartite taxonomy of memory: memory of experiences, of information, and of methods (how-to).<sup>10</sup> Though they apply this schema to examine philosophical questions about when a particular person may truly be said to remember, the schema itself is quite useful apart from this anthropocentric application to taxonomize distinct types of memory, human or machine. Martin and Deutscher’s account is also helpful for calling attention to the distinct preconditions for each type of memory. Remembering demands not only the capacity for memory itself but also a range of other capacities that furnish the inputs and outputs for the act of remembering. For instance, a prerequisite for the memory of experiences is the capacity to have experiences, more particularly a capacity for sensation and perception, as well as the capacity to recall said sensations. This capacity would seem to require some form of embodiment. Likewise, the memory of information requires the capacity to store and recall information semantically; that is, it requires some mode of interaction with language. Finally, memory of methods requires a capacity to recall and implement sequential actions. Yet the faculties that each form of memory presupposes are essentially orthogonal. Memory of methods, for example, does not per force require sensation, perception, or an ability to process language. It is possible, then, to disaggregate these distinct types of memory and consider them separately.

Martin and Deutscher’s tripartite schema is particularly productive if transposed from humans to automata. With it, we gain useful functional differentiations among formats and uses of machine memory, as well as

<sup>9</sup> B. Stiegler, *Technics and Time*, 1, p. 137.

<sup>10</sup> C. B. Martin, M. Deutscher, “Remembering,” *The Philosophical Review*, 75, 2, 1966, p. 161.

an implied hierarchy of sophistication among distinct types of artificial intelligence. For example, memory of information is certainly a function of today's artificially intelligent large language models but also arguably a capacity of earlier information retrieval technologies. Memory of experiences would seem to require some aspect of sensation, implying that certain robots with appropriate sensor arrays may have access to this type of memory but not, for example, AI chatbots. This hierarchy of memory types has some historical relevance and illuminates developmental distinctions in the function of automaton memory, since the forms of machine memory were not developed in the same moment. Indeed, their evolution extends across centuries, arguably beginning with memory of methods, followed by memory of information, and finally memory of experiences, which depends on sensors that can electronically survey the environment.

One may argue that Martin and Deutscher's third category, machinic memory of methods, was first achieved by instruments that play back variable instruction sequences in a way that allowed the dynamic operation of the attached machine. I would argue that this specific type of machinic memory emerged in a particular form: early mechanical encodings of musical automata scores.

#### WATER, ARCHITECTURE, AUTOMATA

Techniques to record information in machine-readable formats developed iteratively over centuries through symbiotic innovations in both notation and media of encoding. Musical automata were significant catalysts for the evolution of automaton mnemotechnologies, as they built on accepted, discretized, and easily serializable musical notation. The scripting of a musical score, and implied the use of a variable notation that, while not precisely linguistic, imposed a definite syntax and structure on encoded musical instructions. The water organ, whose origins date to antiquity, was among the most sophisticated musical automata. It also was among the earliest automata to integrate encoded instruction sequences, and thus arguably ranks among the first machine-readable media. Water organs of the high renaissance also integrated variable programming with the possibility of recoding and reprogramming behavior at will.

Since antiquity, water has been a literal wellspring of automation technologies, a perpetual inspiration for both musical inventors and

architects. The tenth book of Vitruvius (ca. 75 BC–15 BC), specifically devoted to machines, considers water-moving and water-powered machines extensively, including the water wheels (Vitr. X, 5),<sup>11</sup> water pumps (X, 7),<sup>12</sup> and the hydraulis, a precursor to the water organ (X, 8).<sup>13</sup> The hydraulis was a small pipe organ, the first instrument to employ a keyboard, and the beginning of a long iterative development of water-powered musicality. Most of these instruments were much smaller than contemporary organs, many being compact enough to be portable. In the Middle Ages, the Banu Musa brothers of Baghdad (Muhammad, ca. 803-873; Ahmad, d. ninth century; and Al-Hasan d. ninth century) developed a flute that automatically played under power of water. Recorded in their codex *Kitab al-Hiyal al-Naficah* (*The Book of Ingenious Devices*) the Banu Musa flute was among the first machines that employed a pinned drum for the sequential control of the flute. The brothers, who described the device as “the instrument that plays itself,” designed the drums to be swapped out to play a different song. Despite the evident benefits of this novel device, the application of this pinned drum to other instruments in the West took centuries further to be fully appreciated and leveraged.

Despite centuries of development, water organs that could play scores automatically and without human intervention were of a more recent vintage, only fully emerged in the late sixteenth and early seventeenth centuries. The development of water organs during this period, though not exclusively an architectural endeavor, was significantly advanced by architects who, in the Vitruvian tradition, saw infrastructural water works as an integral aspect of their discipline. Indeed, in the early renaissance architecture and hydraulic engineering had not yet diverged, and no less an architect than Leon Battista Alberti (1404–1472) attested to the importance of water in *De Re Aedificatoria*. He, like Vitruvius, devotes a significant portion of his tenth book to the uses and control of water. Aqueducts, Archimedean screws, canals, waterwheels, and dams all fell under the purview of the broadly practicing architect. Historian Pablo Gumiel Campos also observes that Alberti expands on the hydraulic engineering techniques propagated from Vitruvius, including piped

<sup>11</sup> Vitruvius, *The Ten Books on Architecture*, Harvard University Press, Cambridge, Mass., 1914, p. 294.

<sup>12</sup> *Ibid.*, p. 297.

<sup>13</sup> *Ibid.*, p. 299.

distribution.<sup>14</sup> Thus, though their expertise in hydraulic works, architects were well placed to imagine alternate applications of water power.

The late sixteenth century saw a convergence of developments that served to significant advance the sophistication of water automata in general and water organs in particular. This period was a time of exceptionally refined hydraulic works across the European continent, enabled in part by the advent of more sophisticated and powerful hydraulic pump designs.<sup>15</sup> Beyond technical innovations, designers themselves were refining more sophisticated, and quasi-scientific methods in the elaboration of their work. This was encouraged by a deeper familiarity with precedent sources of antiquity, as well as more recent developments in the Islamic world. This wider diffusion of the hydraulic inventions of antiquity contributed to a culture of contemporary innovation in the sixteenth century.

The most significant source from antiquity was Hero of Alexandria (c. 150 AD), the ancient Greek polymath who was arguably the godfather of automata in the West. Hero's work was preserved through several treatises on a range of subjects including *Automata*, *Pneumatica*, *Dioptra*, *Metrica*, *Artillery Construction*, and *Catoptrics*. Still others are attributed to him, uncertainly. From the perspective of automata, Hero's two most salient works were the *Automata* and *Pneumatica*. *Pneumatica*, in particular, proved widely influential and terms of both content and method. Hero framed his work on mechanical invention in quasi-mathematical terms, enumerating theorems and problems in the manner of Euclid's *Elements*.<sup>16</sup> In fact the practice of organizing mechanical research as a series of theorems predated Hero, as Ctesibius of Alexandria (c.300-230 BCE) compiled his own *Pneumatic Theorems*.<sup>17</sup> *Pneumatica* furnished an extraordinary catalog of pneumatic devices that captured the imagination of later generations and secured his place in the pantheon of mechanical inventors. Intriguingly, Hero concluded *Pneumatica* with a description of the construction of a water organ.<sup>18</sup> This organ proved a crucial seed in the later development of musical automata.

<sup>14</sup> P. Gumiel Campos, *Aqua In Palatio: Water in 16th-century European palaces, The Iberian Peninsula as a case study* Vol. 1, (PhD Diss., 2024), 60.

<sup>15</sup> *Ibid.*, 57.

<sup>16</sup> K. Tjebjerg, "Hero of Alexandria's Mechanical Geometry," *Apeiron*, 37, 4, 2004, p. 31.

<sup>17</sup> G. Francesco, *Hero of Alexandria's Automata: A Critical Edition and Translation, Including a Commentary on Book One*. PhD thesis, 2019, p. lxxxvi.

<sup>18</sup> Hero of Alexandria, *The Pneumatics of Hero of Alexandria, from the original Greek*, Taylor, Walton and Maberly, London, 1851, p. 105.

Architects of the sixteenth century Renaissance took a keen interest in Hero's work and contributed to broader experimentation on the principles and methods he espoused. This included rendering Hero's key texts more broadly accessible. In 1589, Italian architect Giovanni Battista Aleotti published a translation of Hero's *Pneumatica* in Italian, the first in a vernacular tongue.<sup>19</sup> Historian A. G. Keller noted that Aleotti had "that taste for the elaborate and the ingeniously cunning in which his age so much delighted."<sup>20</sup> This cultural attraction to ingenuity led to a fascination with Hero's work that peaked around 1580. Aleotti's translation was preceded by Federico Commandino's 1575 posthumous publication of a Latin translation of *Pneumatics*.<sup>21</sup> In fact, Oreste Vannucci Biringucci had prepared an Italian translation by 1582, but it was never published due to his untimely death.<sup>22</sup> Aleotti's translation demonstrated the extent to which architects were significant catalysts in the emerging field of pneumatic and hydraulic automation.

The late sixteenth century also saw ambitious built works that drew on Hero's techniques and in some cases advanced well beyond them. Among the most substantial was an extraordinary water organ at the Villa d'Este in Tivoli that could produce automated music. Though not easily reprogrammable, this organ, constructed in the late 1560s at the direction of Cardinal Ippolito II d'Este, had an unusually sophisticated hydraulic mechanism.<sup>23</sup> Developed by the engineers Claudio Venardo and Luca Clerico, the water organ was also built at an unprecedented scale.<sup>24</sup> Historians Simone M. Kaiser and Matteo Valleriani note that the organ's automated repertoire was fixed and limited, and that the "melody was very short, being composed of only 17 notes."<sup>25</sup> Even this modest feat proved a prodigious marvel to visitors, including Pope Gregory XII. The wonders of this organ indicated a wide latitude of innovation that was yet to come.

<sup>19</sup> A. G. Keller, "Pneumatics, Automata, and the Vacuum in the Work of Giambattista Aleotti," *The British Journal for the History of Science*, 3, 12, 1967, p. 339.

<sup>20</sup> *Ibid.*, p. 342.

<sup>21</sup> S. M. Kaiser and M. Valleriani, "The Organ of the Villa d'Este in Tivoli and the Standards of Pneumatic Engineering in the Renaissance," H. Fischer, V. R. Remmert, J. Wolschke-Bulmahn (eds.), *Gardens, Knowledge and the Sciences in the Early Modern Period*, Birkhäuser, Berlin, 2016, p. 85.

<sup>22</sup> *Ibid.*

<sup>23</sup> *Ibid.*, p. 78.

<sup>24</sup> *Ibid.*, p. 82.

<sup>25</sup> *Ibid.*, p. 89.

By the early seventeenth century, the status of automatons themselves underwent a reputational rehabilitation of sorts. For at least the century prior, automata and their making were held in some suspicion, perhaps because they seemed to take on human faculties mechanically. Yet historian Alexander Marr argues that by the 1620s, “wonder-working” of automatons had emerged from the shadow of occult or magical associations to be understood more broadly as a mathematically informed enterprise of determined rationality.<sup>26</sup> Yet Marr notes that even well into the sixteenth century, automaton inventors could be condemned for sorcery, as was the case with English mathematician and polymath John Dee.<sup>27</sup> The more mathematical the articulation of autonomic theories, the more the automata were rehabilitated from the crepuscular realms of occult magic into the enlightened realm of the sciences. Though the creation of automata was still something of a liminal practice hovering between the practical and the fantastic, it was beginning to gain a measure of rigor and legitimacy.

Despite their dubious reputation, the techniques of automatic music performance were, by the late sixteenth century, well established in the West thanks not only to the musical automata that appeared in the gardens of the nobility but also to the various clockworks and music boxes that populated the *Kunstkammern* of European courts. By the early seventeenth century, the most distinguished and charismatic of these collections already included fairly advanced playback mechanisms such as pinned drums. These devices, derived from the Banu Musa flute and similar mechanisms, used a small metal cylinder with pins protruding radially. When the drum rotated, each pin would pluck one of an array of hammers that struck a bell, plucked a string, or similarly actuated a sonic response. The Habsburg *Kunstammer* of Rudolf II (1552–1612), perhaps the preeminent collection of its kind, featured such intricate pinned drum mechanisms by 1610.

In certain respects, musical automata were a salutary crucible for the development of mechanical memory. The need to record and perform musical scores offered a ready system for the encoding, and the expectations for a certain quality of performance encouraged exacting standards to the playback mechanism of these devices. The courtly interest

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<sup>26</sup> A. Marr, “Understanding Automata in the Late Renaissance.” *Le Journal de la Renaissance*, 2, 1, 2004, p. 207.

<sup>27</sup> *Ibid.*, p. 208.

in automata also provided ample financing and incentive to experiment in this unusual medium. Moreover, music performance was a highly discrete task that nevertheless attracted enthusiasm and curiosity. Ultimately, this confluence of factors, intersecting with parallel developments in hydraulic engineering, led to some of the most significant advancements in machine memory during the seventeenth century.

#### REPROGRAMMABLE MEMORY: SALOMON DE CAUS

At this propitious moment of the scientization of automata, the French architect, inventor, and hydraulic engineer Salomon de Caus developed some of the most ambitious and unusual water organs, devices that drew on spatial and engineering methods to articulate a system of reconfigurable machine memory. In de Caus's work we see a case study of a multidisciplinary inventor leveraging architecture, hydraulic engineering, and the machinery of automation to build devices of considerable ingenuity. Across a career that ranged from England to Germany, de Caus achieved several striking works that bridged engineering and architecture, perhaps none more ambitious than the designs for a vast complex of gardens for Elector Palatine Frederick V. The palatial garden, known as the Hortus Palatinus (Figure 2), was planned to be enlivened by fountains, automata, and other water-driven delights. The Gardens, never fully completed and ruined during the thirty years war, nevertheless attested to de Caus's facility with mechanical invention in the service of design. With the Hortus Palatinus the environment itself became an automaton, a new fusion of mechanism, landscape, and architecture.

More than an accomplished designer and imaginative inventor, de Caus was a gifted systematizer who advanced hydraulic architecture through his significant theoretical work. Most notably, his singular 1615 treatise in hydraulic automation, *Les Raisons des Forces Mouvantes avec diverses machines tant utiles que plaisantes* (Figure 3), is one of the seminal works of the field and arguably the defining text of its kind in the early seventeenth century. The presentation of principles and devices is rigorously organized, with a mathematical style of thinking and presentation pervading the text. De Caus begins with a series of primary definitions, including those for fire, air, water and earth, followed by 18 deductive theorems characterizing the behavior of various machines and assemblies. The method is exactly reminiscent of the way that Euclid built a geometry of deductive reasoning derived from elemental premises. The

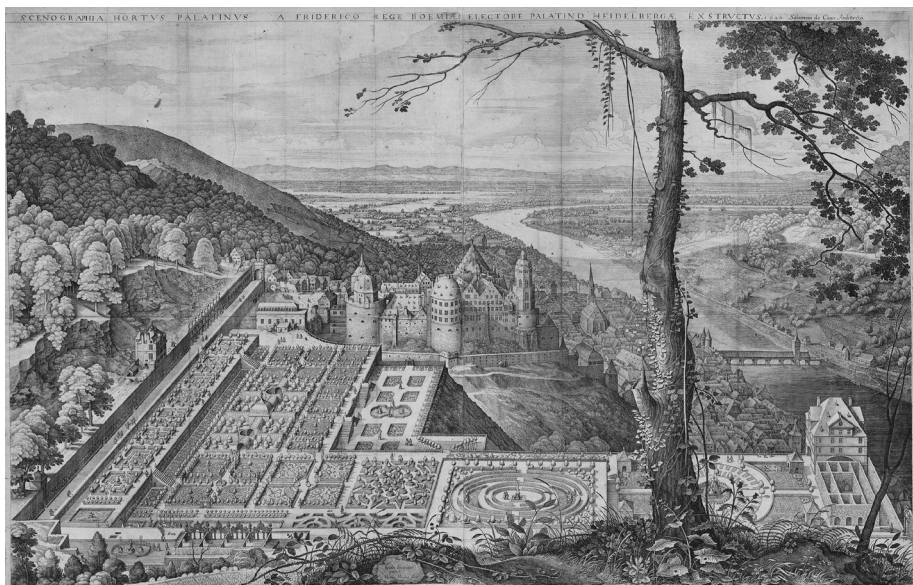


Figure 2. A perspective of the Hortus Palatinus as planned.

Source: S. de Caus, *Hortus Palatinus: A Friderico Rege Boemiae Electore Palatino Heidelbergae Exstructus*, Bry, Frankfurt, 1620.



Figure 3. Frontispiece of de Caus's *Les Raisons des Forces Mouvantes*. Source: S. de Caus, *Les Raisons des Forces Mouvantes, Avec Diverse Machines t'ant Utiles que Plaisantes*, Jan Norton, Frankfurt, 1615.

larger text is divided into three books, each consisting of 35, 20, and 13 “problems,” which were in fact pretexts for ingenious mechanical contrivances ranging including water-driven pneumatic bellows to intricate fountains.<sup>28</sup> These problems draw on the earlier theorems and present increasingly sophisticated machines as the solutions to the stated problems. These theorems thus offered the generative foundation for an extraordinary range of machinery, as well as aligning de Caus’s project tacitly with conventions of mathematical expression and knowledge organization.

Though they collectively deal with the design of mechanized hydraulics works, the three books address different topics. The first book ranges widely in an examination of diverse methods of moving and pumping water, mechanisms of water clocks, techniques of fountain design, water-driven wood fabrication tools, and water organs, including descriptions of de Caus’s method for storing and reading scores. The second book is devoted particularly to the architecture of fountains, grottoes, and follies that might house delightful automata. The third book delves more fully into organs and organ-making, including the fabrication and proportion of pipes, the use of bellows, and the design of water wheels. Throughout, de Caus furnishes a series of marvelous plates that bring his inventions to life with exquisite detail.

Among its many innovations, *Les Raisons des Forces Mouvantes* elaborated de Caus’s technique of machine memory: a reprogrammable pinned drum (Figure 4). Through his text and a series of marvelous analytic drawings, de Caus describes a large cylinder (“roue musicale”) with a horizontal axis furnished with a grid of holes to which various rectangular pegs could be affixed.<sup>29</sup> These pins would strike keys of a keyboard or other mechanical relay as the cylinder rotated, thereby opening the stops of associated organ pipes (Figure 5). The various lengths of the pins corresponded to different durations of activation for the connected pipes, and some were cut to fine points to allow instantaneous plucking of the keys. In order to allow dynamic reconfiguration, the cylinder was perforated with a series of holes that allowed the pegs to be “change the pegs when one would like to change the song.”<sup>30</sup> Thus unlike the pinned drums of the Banu Musa and other predecessors, de Caus’s drum was

<sup>28</sup> S. De Caus, *Les Raisons des Forces Mouvantes, Avec Diverse Machines t’ant Utiles que Plaisantes*, Jan Norton, Frankfurt, 1615.

<sup>29</sup> Probleme XXV, *ibid.*

<sup>30</sup> [...] “changer les cheuilles quand l’on voudra changer de chanson.” Probleme XXX, *ibid.*

reprogrammable at the level of the individual notes, allowing for editing and modification without the wholesale replacement of the drum. Arguably, this was one of the first instances of reprogrammable machine memory. Drawings of this apparatus indicate 30 notes, a narrower range than the contemporary harpsichord but nevertheless one that afforded broad combinatorial possibilities in musical performance. Moreover, this type of reconfiguration—the rearrangement of pegs in a large drum—required that the pegs themselves should be of sufficient size to be manually manipulable. Thus, to allow for reconfiguration, de Caus's device necessarily approached the architectural scale of a large room or even a building. In a way, reconfigurable machine memory invited architectural thinking.

Two aspects particularly distinguish de Caus's organ from its predecessors. First, the scale of his proposed water organs was substantial, taking on architectural dimensions. Although the exact size of these devices is not explicitly stated, tacit indications such as the inferred dimensions of the drawn brick enclosure confirm that this is a proposal at a building scale.<sup>31</sup> Moreover water organs required larger and more robust mechanisms than the delicate devices of small courtly automata, so a larger scale is in keeping with those demands. To a degree, De Caus was designing public automata, or at least automata that were housed in their own building enclosures and thus had a different kind of presence than those safely locked in a courtly *wunderkammer*. They were artifacts of a larger design ambition for the palace as a whole. Second, de Caus devised a system by which the scores could essentially be reprogrammed through a rearrangement of variable pegs on a fixed drum. While the pinned barrel, was, by the seventeenth century, one of the conventional mechanisms for the automatic production of music, most prior devices had pins permanently attached to the drum. Thus, any modification of the drum necessitated the full replacement of one pinned drum with another. At an architectural scale of de Caus's organ, this would have been wholly impractical. De Caus's method allowed the dynamic change of even editing of sections of the score, on a large common drum. In effect, he developed one of the first systems of reprogrammable machine memory.

The principles of de Caus's work were widely influential, not only in terms of hydraulic engineering but also as precedents for the automata that entertained the courts of Europe. Aside from its immediate influence on water automata, the pinned drum mechanism was also a tangible

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<sup>31</sup> *Ibid.*

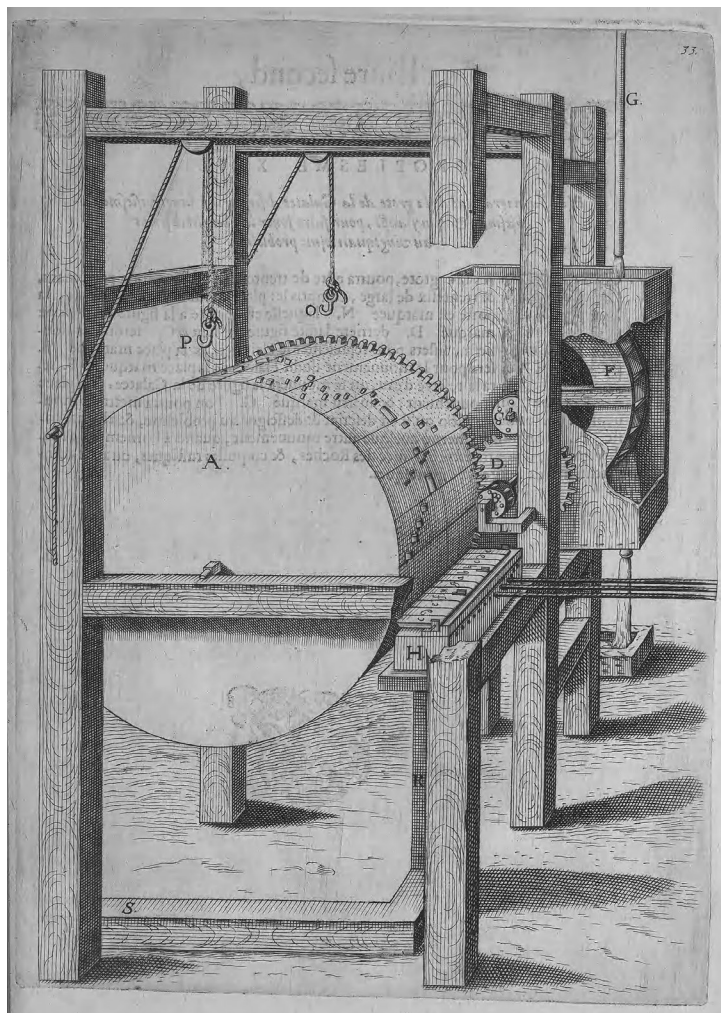


Figure 4. A perspective of de Caus's organ, showing the drum, keyboard, and driving mechanism. Source: S. de Caus, *Les Raisons des Forces Mouvantes, Avec Diverse Machines t'ant Utiles que Plaisantes*, Jan Norton, Frankfurt, 1615.

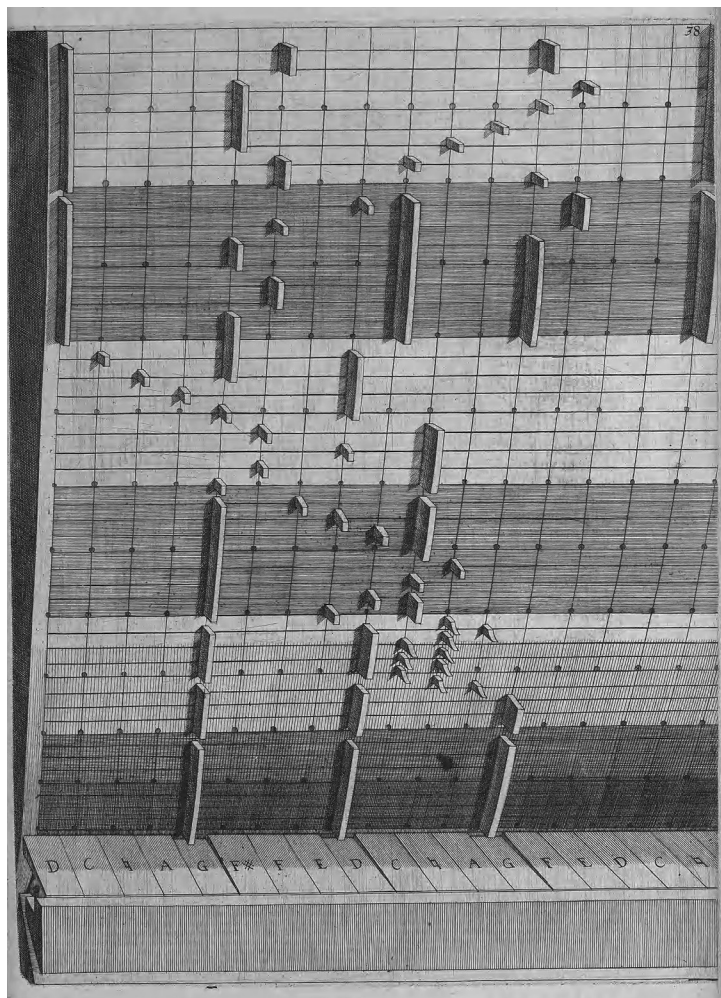


Figure 5. A detail of the reconfigurable pegs on the larger cylindrical pegboard of de Caus's organ. Source: S. de Caus, *Les Raisons des Forces Mouvantes, Avec Diverse Machines t'ant Utiles que Plaisantes*, Jan Norton, Frankfurt, 1615.

precedent for the Jacquard Loom and later punch card methods of automated tabulation and calculation. Though he did not overtly describe his work in these terms, de Caus showed the capacity of tectonic thinking to advance automation and, in particular, endow automata with marvelous new memory.

In some curious respects, de Caus's work paralleled Libeskind's later Memory Machine. The robust wooden frames, obvious musical associations, and geared articulation give the two a certain formal affinity. They also represent the polarities of human and machine memory. Though highly machinic in its articulation, Libeskind's aleatoric work suggests a dream state of human memory, with a tangible but mysterious structure. In contrast, de Caus's organ exhibits a strict organization that communicates its machine legibility. Yet both ultimately exist in the liminal space between technology and space, artifacts that probe the possibilities of artificial memories through architectural imagination.

#### THE ARCHITECTURE OF MACHINE MEMORY

In 1813, none other than the eminent German composer Ludwig van Beethoven (1770–1827) set out to write a piece commemorating Napoleon's Waterloo defeat not for orchestral performers but for an elaborate musical automaton: the Panharmonicon.<sup>32</sup> This extraordinary device, capable of reproducing the sounds of a small orchestra, as well as gunshots and cannons, was the invention of Johann Nepomuk Mälzel (1772–1838), Beethoven's erstwhile patron. Mälzel was a polymathic showman and one of the most charismatic and prolific inventors of musical automata of the early nineteenth century. An itinerant exhibitor around Europe and later the United States, he was credited with a wide range of musical machines. He popularized a variant of the metronome, though his claims to have invented it were questionable.<sup>33</sup> Ever the showman, Mälzel acquired the Mechanical Turk, the legendary false automaton in which a grandmaster chess player would sit, concealed, and play an unsuspecting opponent, guiding what appeared to be the actions of an automaton.<sup>34</sup> Mälzel purchased the Turk from its original inventor,

<sup>32</sup> T. Riley, "Composing for the Machine," *European Romantic Review*, 20, 3, 2009, p. 368.

<sup>33</sup> "Observations upon the Automaton Chess Player, now exhibiting in this city, by Mr. Maelzel, and upon various Automata and Androides," *The Franklin Journal and American Mechanics Magazine*, 3, 1827, p. 132.

<sup>34</sup> *Ibid.*, p. 130.

Baron von Kempelen, who created it in 1769 and subsequently exhibited it widely.<sup>35</sup> Unfortunately, the collaboration ended in a scandalous lawsuit in which Beethoven accused Mälzel of falsely claiming the rights to Beethoven's piece.<sup>36</sup> Mälzel, for his part, surreptitiously inscribed Beethoven's partial score on a recording cylinder, which he then used at performances of the Panharmonicon for years.<sup>37</sup> If one were to consider Beethoven's score as a kind of software for the Panharmonicon, the conflict might be considered an early hint of software copyright disputes to come.

Despite the acrimonious conclusion of this episode, the fact that an artist of Beethoven's reputation was willing to compose for a mechanical automaton shows not only the degree to which musical mechanisms had become a culturally accepted or even mundane aspect of the material culture of the early nineteenth century. It also indexes the extent to which the technology of recording and programming the actions of automata—particularly through means such as pinned cylinders—had been diffused and applied in a range of contexts. In the nearly two hundred years since the designs of the water organ of de Caus, automatic musical instruments—and the artificial memory they employed—had become part of the wider culture. Historian Terrance Riley noted that “By 1800 even the minimally-informed knew that all true automata, both anthropomorphic and non-anthropomorphic, were fundamentally musical machines—that beneath the costume of the android and the cabinet of the music box lay identical, and quite familiar, clockwork mechanisms,” mechanisms of artificial memory.<sup>38</sup>

In the two hundred years since Beethoven, machine mnemotechnologies advanced enormously. The pinned cylinders of de Caus and others became direct progenitors of wax recording cylinders, phonograph records, hard and floppy computer disks, compact disks, and the entire family of computational storage that followed. Born of the entanglement of wonder-making and engineering, they occupy a remarkable position as a moment of convergence between architectonic thinking, automated performance, and emerging formats of mechanized memory. In very real respects, musical automata set in motion the possibility of machine memory that is now foundational to our technological culture.

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<sup>35</sup> *Ibid.*, p. 125.

<sup>36</sup> T. Riley, “Composing for the Machine,” p. 370.

<sup>37</sup> *Ibid.*

<sup>38</sup> *Ibid.*, p. 369.

The imaginings of de Caus may seem far removed from the micro-electrical switching and hyperscale digital memory that powers today's computational automatons. Indeed, water and hydraulic automation has been relegated to something of a byway in the history of technology, long superseded by electricity and silicon. Yet occasionally, the abortive lineage of water organs as computational device resurfaces, to intriguing effect. William Phillips's 1949 MONIAC (Monetary National Income Analogue Computer), a device that used water flows to simulate macroeconomic scenarios, is a well-known example. Through a series of gates and flues, an operator could alter the distribution of funds in a dynamic simulation of the national economy of the UK.<sup>39</sup> MONIAC might be seen as a kind of water organ for playing the economy in simulation. Speculative visions of water-computing devices have also periodically enlivened architectural speculation. American architecture collective Ant Farm's well-known Dolphin Embassy project featured a powered by water and operated by dolphins.<sup>40</sup> More pragmatically, new technologies like microfluidics and "lab on a chip" devices offer a kind of return to mechanistic fluid engineering at an impossibly tiny scale, a kind of de Causian hydraulics in miniature. Perhaps we have not seen the last of water in computational automata.

Beyond its contribution to water-powered automata and its advancement of machine memory precursors, de Caus's work prompts reflections on alterities of automated architecture. How would architecture itself have been different if de Caus's inventions had been integrated into the disciplinary repertoire? What if the pinned drums and automated actuation had driven the behavior of the building itself? What if not only automata but buildings themselves gained a mechanical memory? As an architect, it seems at least possible that de Caus may have mused on such questions. If those consequences had been played through, one could imagine entire buildings driven by kinetic scores, coming alive in animated reverie. Finally, de Caus's trajectory also offers one index of the fluid boundaries of early modern architectural disciplinarity that led to remarkable experiments in kinetic automation. De Caus represents an intriguing moment of alignment between architecture and proto-computational automation, a moment which mechanical memory became nearly architectural.

<sup>39</sup> C. Bissell, "Historical perspectives: The Moniac A Hydromechanical Analog Computer of the 1950s," *IEEE Control Systems Magazine*, 27, 1, 2007, pp. 69–74.

<sup>40</sup> A. Witt, "An A(I)lien Embassy," *AD: Architectural Design*, 94, 3, 2024, pp. 54–61.

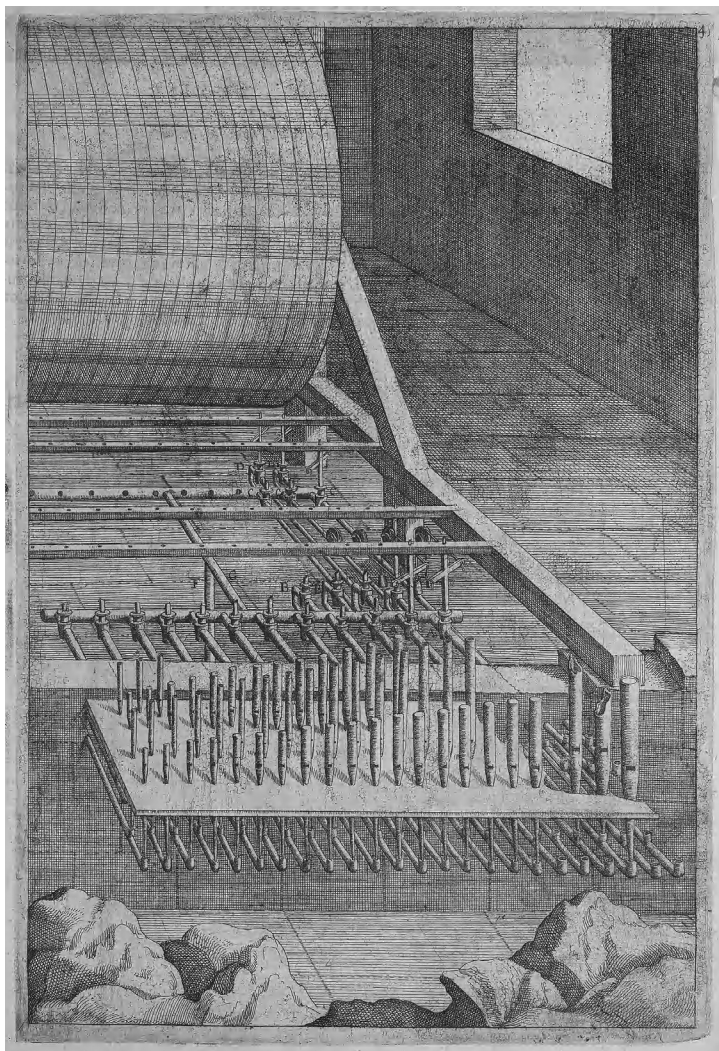


Figure 6. Details of the pipework for de Caus's organ.  
Source: S. de Caus, *Les Raisons des Forces Mouvantes, Avec Diverse Machines t'ant Utiles que Plaisantes*, Jan Norton, Frankfurt, 1615.

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