Form and Data

from linear Calculus to cybernetic Computation and Interaction

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Digital architecture developed in the 1960s and, supported by CAAD the 1990s, has created the path towards an architecture produced by computer and architect in a mutual relationship. The evolution of architecture since the 1970s led to the beginning of the first digital turn in the 1990s, and subsequently to the emergence of new typologies of buildings, architects and design tools; atom-based, bit-based (virtual) [1], and cyber-physical as a combination of both. The paper provides an insight into historical foundations of CAAD insofar as it engages with complexity in mechanics, geometry, and space between the 1600s and 1950s. I will address a selection of principles discovered, and mechanisms invented before computer-aided-architectural-design; those include the typewriter, the Cartesian grid and a pre-cyber-physical system by Hermann von Helmholtz. The paper concludes with a summary and an outlook to the future of CAAD challenged by the variety of correlations of disparate data sets.

Keywords: *HCI, cyber-physical systems, cybernetics, digital history, computational architecture, Helmholtz*

The paper *Form and Data: from linear Calculus to cybernetic Computation in Interaction* aims at furnishing the current discourse on how to handle the overwhelming combination and integration of big data, intelligent materials, artificial intelligence and machine learning, interacting structures, and optimization of typologies and geometries. It is structured in four sections. The first section contextualizes the topic and illustrates the subject in the problem of code, behavioural patterns, and interaction leading to the increased relevance of relations of digits over discrete signs, using the typewriter as an example. Section two introduces **Descartes'** Cartesian grid as a first step towards the digital using variables and functions. Section three discusses a predecessor of cyber-physical systems, the *Frog Drawing Machine*. Based on a kymograph, Hermann von Helmholtz developed a first complex interaction machine, transforming real-time bio-data into visualization. Section four introduces the typewriter as interactive spatial form-generator, interface and decoding device at the same time, followed by the conclusion.

CONTEXT

The machines and concepts introduced dwell in times, in which the human provided feedback to the machine for it to become cybernetic. Firstly, through the new concepts and also physically new interfaces of how we humans interacted with the new world that was about to emerge. Navigation machines offered the possibility of predicting where to move in space and added to intelligent warfare. Transport machines changed the understanding of the relationship between space and time was radical. The world started to become smaller, globalization commenced. Secondly, not only the concept but the immaterial existence of programming, of algorithms, hence software had its starting point in exactly the very era of the 17th and 18th century. The advent of the computer-hand in hand with discoveries in quantum physics-has offered the possibility to elevate the species of trivial machines to machines and concepts that could encode, decode and/or teach machines. Concepts unknown and unthinkable at that time. Assumingly, complexity in mechanics, geometry and space has been shaped directly and indirectly by the thoughts, inventions and theorems, mathematics and the philosophies of Aristotle, Plato, Euclid, Descartes, Boole and many more. Their mathematical-philosophical approach describes a pre-requisite to trigger teleological changes for cultural operations like a cybernetic machine.

Topics related to the cybernetic, the digital and computational in architecture have been developed since the early 1960s through projects such as the IBM Pavilion at 1964 at the New York World's Fair designed by Charles and Ray Eames or Ivan Sutherland's Sketchpad (1963) developed at MIT describing the interface between the two 'alien' species - 'human' and 'machine' - the Human-Computer-Interface (HCI). The *Colloquy of Mobiles*, an interactive structure developed by the British cybernetician Gordon Pask, followed suit in 1968. (Pask, 1971) Nicholas Negroponte (MIT) actively combined architecture, urban design, computer sciences and biological principles culminating in the emergence of projects presenting self-organization (Negroponte, 1970) and generative/iterative evolution rather than designing projects of finite geometry or function. Throughout the history of information exchange, especially in the late 20th Century, a transgression of computation from the virtual and arithmetically combinatory to the material, cultural and spatial can be witnessed. Architecture has experienced this transgression mainly through a growing interest in and application of digital devices performing digital operations with a more or less outcome of complex geometries and forms, which were hardly possible to control before 'intelligent' calculating machines. Algorithmic architecture as a linear input-to-output operation is being replaced by the complexity of parametrics (see Frazer, 1995) - a technique for creating infinite variations of form in advanced architectural geometry - acting upon the production of architecture. (L. C. Werner, 2018) Current times, in which the Anthropocene, big data, digitization, and machine learning describe prominent societal, economic and design parameters, architects, theorists and practitioners from many disciplines respond to the demand for re-thinking how to implement them and design and how to build; not to forget the relevance of advanced, possibly intelligent, bio-computational materials.

FOUNDATION 01
Descartes and Geometry

The idea appeared in the 17th century. Descartes invention of the Cartesian coordinate system in 1637 communicated geometry as functions to be represented on a two-dimensional Euclidean plane or in a three-dimensional Euclidean Space. Physical space was then and is generally still defined according to Euclid. Euclidean elements and Euclidean geometry developed approximately 300 B.C. has described the basis of the understanding of geometry we still use to date. At the end of the 20th century, the question of curved space, n-dimensional space and non-linear/non-Euclidean Space was discussed widely. Hilbert describes the Euclidean elements (systems of things) and corresponding axioms (rules) in chapter 1 of *Grundlagen der Geometrie*, 1913 as follows:

"We think of three different systems of things: the things of the first system we call points and denote them by A, B, C, ...; we call the things of the second system a straight line and denote it by a, b, c, ..., the things of the third system are called planes, and we denote them by a, ß, y, ...; the points are also called the elements of the linear geometry, the points and lines are called the elements of the plane geometry and the points, lines and planes are called the elements of spatial geometry or space. We think of the points, lines, planes in certain interrelations, and refer to those relationships by words like ″lie,“ ″between,“ ″parallel,“ ″congruent,“ ″steady,“ and the exact, and for mathematical purposes, complete description of those relationships through the axioms of geometry.″ (Hilbert, 1913) p.14

(Original text: "Wir denken drei verschiedene Systeme von Dingen: die Dinge des ersten Systems nennen wir Punkte und bezeichnen sie mit A, B, C,...; die Dinge des zweiten Systems nennen wir Gerade und bezeichnen sie mit a, b, c,...;die Dinge des dritten Systems nennen wir Ebenen und bezeichnen sie mit a, ß, y, ...; die Punkte heißen auch die Elemente der linearen Geometrie, die Punkte und Geraden heißen die Elemente der ebenen Geometrie und die Punkte, Geraden und Ebenen heißen die Elemente der räumlichen Geometrie oder des Raumes. Wir denken die Punkte, Geraden, Ebenen in gewissen gegenseitigen Beziehungen und bezeichnen diese Beziehungen durch Worte wie ″liegen“, ″zwischen“, ″parallel“, ″kongruent“, ″stetig“; die genaue und fu⍰r mathematische Zwecke vollständige Beschreibung dieser Beziehungen erfolgt durch die Axiome der Geometrie.″ (Hilbert, 1913) p.14)

Descartes, at the end of the 17th century, extended the field of geometry to algebra by introducing relations. The Cartesian coordinate system allowed to describe each possible point in space and its relationship to one or more points in the coordinate system. Essentially. By having the possibility to describe each point in a coordinate system, Descartes enabled he describe essentially shapes of formulas; the coordinate system is the virtual space in which an algebraic numerical formula is translated into a form. The coordinate system-its logic-is the operator for the translation of information from a numerical form to a graphical form. A point on a two-dimensional plane would be defined by the two axes that defined the quadrant(s) of where the point was located. The X and Y axes determined the boundaries of the plane by combining two positive fields and two negative fields, the value on each axis determined the variable for the function. The relation of all values described form in the language of analytic geometry. Figure 1 shows the translation of the algebraic function of a circle to the graphic form in a Cartesian coordinate system; a Cartesian coordinate system with a circle of radius 2 centered at the origin marked in red. The equation of a circle is (x – a)2 + (y – b)2 = r2 where a and b are the coordinates of the center (a, b) and r is the radius. [2]

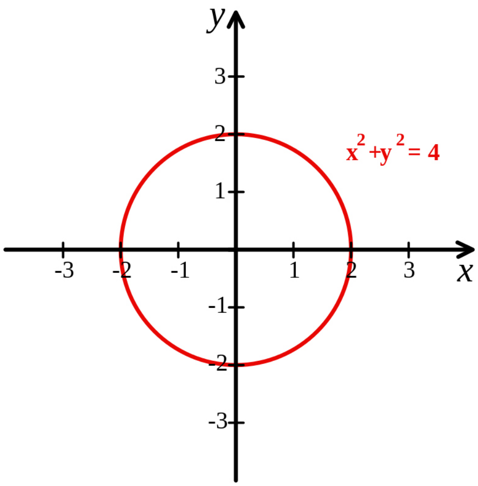

Figure 1
Cartesian coordinate system
[1]

In contemporary computational architecture the debate of body (object), force (function or code of form) and spatial configuration (position of the object in space) has a longstanding tradition. Descartes enforced the Aristotelian idea of space being body by creating an infinite three-dimensional space. For Descartes, a body in space could not be separate from space itself "the extension in length, breadth, and depth which constitutes the space occupied by a body, is exactly the same as that which constitutes the body” (Pr II 10). (Slowik, 2014) He continues his argument of the Cartesian space by developing a heliocentric cosmological system using gravity, where each planet moves according to gravitational force. *The Principia Philosophiae*, published in Amsterdam in 1644 shows a diagram (Fig. 2) of the plenum vortices that describe this behavior. (Descartes, 1644) For Descartes, the cosmos was a giant mechanical machine where single elements acted together.

It is superfluous to say that the invention of perspective and later the invention of the gridded computer-screen are Cartesian coordinate systems. The Descartes model of the cosmos-which he transferred to all moving bodies and substances-shows a close relationship to geometry logics with algorithms featuring attraction and repulsion. Researchers, architects and engineers apply such algorithms to Multi-agent systems, systems e.g., geometric optimization or structural optimization alike; commonly used in digital parametric architecture. The form of Voronoi and Delaunay geometry is visible. In the field of parametric architecture, the logic of both, Delaunay and Voronoi algorithms has been used widely in the generation of architectural form. Their primary feature is that cell size and location change as soon as the location of one element in the network changes. Voronoi and Delaunay diagrams are parametric nature. Descartes inventions point strongly to an understanding of space as a construct created by a series of parameters and functions, which suggests adaptability and interaction. An understanding that is close to the observations Wentworth D’Arcy Thompson in *On Growth and Form* (Thompson, 1942) and soap bubble experiments by Frei Otto’s.(Otto, Trostel, & Schleyer, 1973) With the developments and inventions by Rene Descartes, computation entered a domain of malleable space, differentiation and the generation of form.

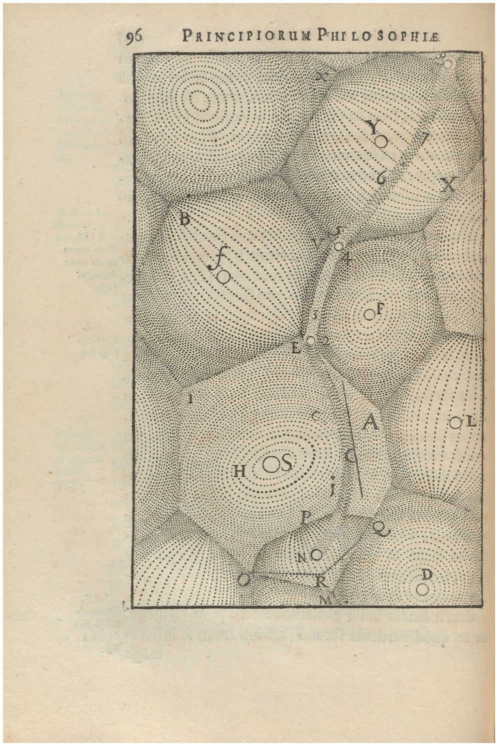

Figure 2
Source: Gift of Dan Siegel (Class of ‘1957) to the History of Science Collection Rene Descartes, “Principia Philosophiae,” Hay Exhibits, Amsterdam: Apud Ludovicum Elzevirium,1644. [3]

FOUNDATION 02
The Frog Drawing Machine

On a physical rather than geometric level I would like to draw from the typology of ‘mechanical apparatus’ invented in the 19th Century. Around 1850, Herman von Helmholtz (born in 1821) investigated how the communication between a stimulus and a muscle was technically and mechanically constructed. His goal was on the one hand to find a way to measure the velocity of electricity travelling through a nerve and on the other to understand the relation from stimulus to action. Helmholtz wanted to discover “in what length of time and stages the energy of the muscle rises and falls after momentary excitation.” (Wise, 2008), (H. Helmholtz, 1850) In order

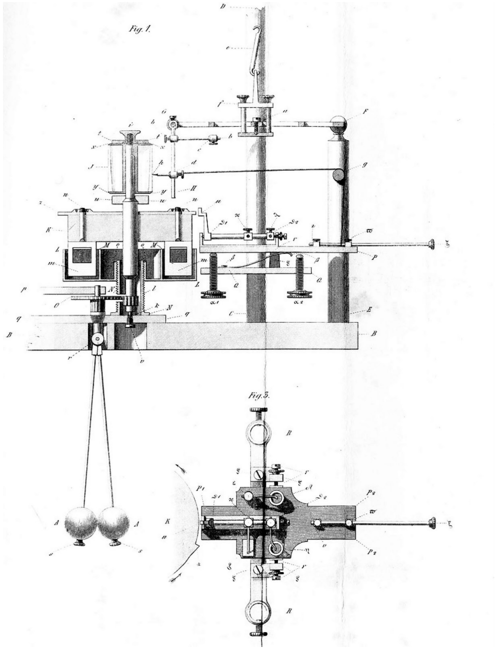

Figure 3
Drawing of one of Hermann von Helmholtz's Myographs, copper etching, 1852
Hermann von Helmholtz (1852): „Messungen über Fortpflanzungsgeschwindigkeit der Reizung in den Nerven"

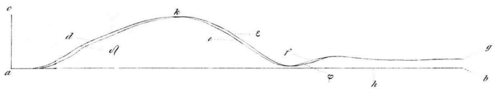

Figure 4
Hermann von Helmholtz (1852): „Messungen über Fortpflanzungsgeschwindigkeit der Reizung in den Nerven". Archiv für Anatomie, Physiologie und wissenschaftliche Medicin, p. 199–216, Plate VII

to record the neurological phenomenon of muscle stimulation of a frog's calf, Helmholtz designed and developed a myograph, the *Froschzeichenmaschine* (Frog-Drawing Machine). The apparatus, a myadynamometer or Myogrpah, was designed in a way, that the muscle movement triggered a drawing device, that would directly draw a curve-isomorph to the intensity of the contraction and relaxation. Figure 3 shows a plan and section of one of Helmholtz's myographs. The Froschzeichenmachine (Frog Drawing Machine) visualized data real-time and thus, allowed the operator to analyze data without timedelay. It was an encoding machine, used for transferring the effect of an electrical impact on the muscle into a graph. The new graphical method-later identified with Etienne-Jules Marey-enabled to show and record medical information; the typology Diagram (Zahlenbild). Gödde describes the Kymographion, the heart of the mechanics invented by Carl Ludwig (translated from German): "It is a cylinder, covered with smut paper, on which a feather tip engraves lines.". (Original text "Das ist ein rotierender, mit berußtem Papier bespannter Zylinder, auf den eine Federspritze Linien einschreibt."). (Gödde & Zirfas, 2018) Figure 4 shows the result of the operation. Engelschalt explains (translated from German) "The distance between a and h corresponds to one revolution of the writing surface and thus 1/6 second. Accordingly, space as relative time differences is measured. The horizontal line between a and at the beginning of the curve corresponds to the latent phase of muscle irritation. The spatial difference of the two curves with respect to the abscissa axis (technical formulated: the phase shift) corresponds to the duration of a pulse through the frog nerve (channel time)." (Engelschalt, Maibaum, Engels, & Odenwald, 2018)

The kymograph, he states, is a device that automatically translated the current state of a body into a graphical diagram; to be used in medical experiments. While Gödde focuses on ethics and notions of privacy during a medical experiment, our focus is the computation the device executed. It was not equipped with an immaterial software as we know it today but had the software embedded in the hardware. The apparatus opened a new understanding of automation. Automation, as carried out through the Froschzeichenmachine, made invisible visible and overlapped bio-data with matter and space. A machine - to start big data and corresponding data analysis - was born. The curves form simultaneously to the activities performed by the living specimen. The Froschzeichenmaschine was a first cyber-physical systems. Parameters that informed the geometry of the curve and thus, also its aesthetics, were firstly the strength of the electric current and the physiognomy of the muscle, and secondly the nature of the material that created the curve physically. In case one of the primary parameters changed, the curves would have a different form. A parametric setup resulted in the curves. It was impossible to foresee their final curvature and the aesthetics of the visualized data - even if the configuration of the system and the relationships of the components in the system were planned and pre-set. Norton M. Wise emphasizes that for Helmholtz the actual form of the Form, the aesthetics and beauty of the Form as well as the intricacy of the line where of high importance. Wise states the passion of Helmholtz-stated during his lecture at the Academy of Art in Berlin-of making the dynamics of the muscle's movement visible, even in a still drawing: "Human models maintaining fixed poses, he [Helmholtz] observed, display nothing like "the Forms of the moved body" in its capacity to act. "The artist must know which muscles swell with the motion ... of their figure should not see, to stand still like a model." (H. v. Helmholtz, 1850) in (Wise, 2008)

FOUNDATION 03

The Typewriter

Historically the shift-with focus on human-computer/machine-interface-and related operations, such as writing, changed dramatically after the invention of mechanical machines, like the typewriter. Instead of creating a word, sentence or text physically in a linear fashion, the word, sentence or text was created spatially on a limited space, combining signs (the letters). The spatial configuration and hence the form of the information, namely the word and the function of the operation feeding back to the human body and the cognitive understanding of what this operation was shifted from linear to systemic. The machine typology the typewriters represent is different; insofar, as it integrates the human. Without the input of the human using the typewriter's keyboard, the typewriter cannot function, and no result can be generated. It combines a physical interaction, with an immediate output while an operation of navigation is leading the act (of writing). Knowledge, or let's call it information, was transported from the human data storage - the brain - via a strict and significant movement or rather orchestration and clear process of finger and hand movement via the medium of the mechanical typewriter onto another data storage, paper. Writing machines enabled an interplay of the physicality of a trivial machine (Foerster, 2003), the human biological organism, its mechanical capabilities (moving fingers, hands and arms) and in the human users' cognitive cerebral system. We may be courageous and suggest that there is an interaction with the typewriter-as there is an interaction with a bicycle. Why? Because body and mind are direct parts of the function, of the operation of the machine. The trivial machine and the non-trivial machine of the human merge into one functioning unit (Funktionseinheit). Operations, such as writing, carried out through the medium of the mechanical cybernetic machine changed the mathematical function of the operation feeding back to the human body and the cognitive understanding of what this operation is after the invention of a cybernetic machine. Additionally, the spatial configuration and hence the form of the information, namely the word, shifted. In Aufschreibesysteme Friedrich Kittler engages with the relationship of space and discrete entities, in this case, letters and signs and states that a geometric form as a result of combining letters in a spatial system replaces the figure, that was created through hand-writing. (Friedrich A Kittler, 1995) A digital mechanism that, in 1888, lead to the introduction of a universal layout of the keyboard. The typewriter soon became a widespread tool to increase efficiency in creating and copying written documents. The industry had to find ways to ease the use of using the tool. Kittler describes that (translated from German) "Spatially defined and discrete signs-and this is beyond all acceleration the typewriter. The word-figure (in case of handwriting) is replaced by the imagination of a geometrical figure, a result of the spatial location to the letter-keys. The significant is defined by unique relationships to the place: Different to all that is real, the significant can be at a place or not. This is the reason why immediately after the launch of the typewriter a powerful movement in favor of the introduction of a universal keyboard emerged. As a result, the *Congress of Type-Writers* agreed upon a universal keyboard in Toronto, 1888." (Friedrich A. Kittler, 1995) The typewriter and the decision to agree upon a specific format of the universal keyboard reflects, on the one hand, automation of writing itself, disregarding glitches and beauty within personal handwriting, and on the other hand, this development pushed the idea of digits, the digital and the significant to a large extent. Digitization of knowledge, at this time still far from being binary but close enough to suggest the advent of the digital age with its mechanization and its mechanics at the same time. The path from the typewriter, the interface between the imagined and the real, to the digital universal keyboard and finally to direct input on the screen started to appear. The notion that the right combination of discrete objects in space (a function) results in a form (a word or a geometric form itself) as a system is one of the drivers for computational architecture.

CONCLUSION

The history and the future of CAAD go back well beyond the introduction of the computer for digital and computational design strategies. The concepts derived through the combination of early mechanics, geometry, navigation, physiology have influenced current innovative streams in computational design. I argue that using the tools provided by computer-aided architectural design goes beyond the computer as an assistant. The physical biological body had been involved in the generation of the form before computers and will, in a next iteration, merge with the digital; in order to operate the behavior of our building and cities. A further step will include the integration of bio-computers (Marks, 2013), (L. Werner, 2019)-already researched on in the 1970s (Asaro, 2007)- to enhance cyber-physical systems with distributed robots (Hamann et al., 2017), intelligent building skins and computational materials integrated into our habitats. (Dade-Robertson et al., 2016) I would like to differentiate between the two approaches, one relates to an increasingly complex network combining buildings, bodies and construction, another relates to the nature of the actual computers and the way they will compute (Adamatzky et al., 2019), a third one to an architectural aesthetic AND behavior that operates according to biological principles.

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