Fig. 1.

Fig. 3.

Fig. 2.

# Big Data and the End of History

Mario Carpo

**Abstract**: As data storage, computational processing power, and retrieval costs diminish, many traditional technologies of data-compression are becoming obsolete. This unprecedented state of data opulence, where more and more data are expected to be always more easily available at ever decreasing costs, is bringing about significant changes in contemporary computation, and fostering a revival of Artificial Intelligence technologies that were seen until recently as of limited practical use. A similar techno-cultural disruption is already conspicuously affecting architectural design. Informational models in three dimensions are replacing the basic tools of the designer's trade since the Renaissance – scaled drawings in plans, elevations, and sections. Furthermore, Big Data and computation allow digital designers to compose and engage with the messiness of some natural processes without going through the traditional mediation of abstract and general mathematical theories and patterns. Just like computation is replacing the causal laws of modern science with the brute force of data-driven simulation and optimization, blunt information retrieval is increasingly, albeit often subliminally, replacing causality-driven, teleological historiography, and demoting all modern and traditional tools of story-building and story-telling. This major anthropological upheaval challenges our ancestral dependance on shared master-narratives of our cultures and histories.

**Keywords**: Data compression technology, 3D modeling, digitally intelligent design, post-spline digital style

# Introduction[1]

At the time of writing, in the summer of 2014, *Big Data* is a cultural trope more than a technical term.[2] Yet the expression originally referred simply to our technical capacity to collect, store, and process increasing amounts of data at decreasing costs, and this original meaning still stands, regardless of hype, media improprieties, or semasiological confusion. Historians of information technology would be hard pressed to see this as a novelty: Moore's law, which describes a similar trend, has been known since 1965, and it holds true to this day. Yet, even more than the adoption of the term by specialists and in some professions, the "Big Data" phenomenon indicates that some crucial qualitative threshold may indeed have been crossed of recent—or at least, suggests a general belief that it may soon be. And there may be more to that than media hype. Today, for the first time in the history of humankind, data is abundant and cheap, and getting more so every day. If this trend continues, one may logically infer that at some point in the future

Figure 1: Gaspard Monge, Géométrie descriptive. Augmentée d'une Théorie des ombres et de la perspective: extraite des papiers de l'auteur (Paris : Courcier, 1820), 189.

an almost infinite amount of data could be recorded, transmitted, and retrieved at almost no cost. Evidently, a state of zero-cost recording and retrieval will always be impossible; yet this is where today's technology seems to be heading to, asymptotically. But if that is so, then we must also come to the inevitable conclusion that many technologies of data-compression currently in use will at some point become unnecessary, as the cost of compressing and decompressing the data (sometimes losing some in the process) will be greater than the cost of keeping the raw data in its pristine state for a very long time, or even forever. When we say data-compression technologies, we immediately think of JPEGs or MP3s. But let's think outside of the box for a second.

# Data-Compression Technologies We Don't Need Anymore

Big Data, which many today see as a solution, was more often a problem throughout the history of humankind. For example, hand-processing big numbers with traditional arithmetic tools takes time and effort—and the bigger the numbers, the higher the risk of errors. Hence that glorious invention of baroque mathematics, logarithms, which use tables of conversion in print to turn big numbers into small numbers, and the other way around; and, crucially, convert the multiplication of two big numbers into the addition of two smaller ones. Laplace, Napoleon's favorite mathematician, famously said that logarithms, by "reducing to a few days the labor of many months, doubled the life of the astronomer."[3] As well as, we may add, of many twentieth-century engineers: logarithms are at the basis of that other magical tool, the slide rule, whereby engineers of the twentieth-century could calculate almost everything in almost no time. But, even though I myself still studied logarithms in school for many months, I never learned to use my father's slide rule, because by the time I was fifteen I could buy a Texas Instruments pocket calculator for next to nothing. That worked much faster and more precisely than all the logarithmical tables and slide rules combined. Today, logarithms are a relic of an age gone by: a fascinating chapter in the history of early modern mathematics, which no astronomer or engineer would waste time on. Logarithms are a technology of data compression we don't need any more.

To take another example closer to the daily life of today's design professionals: scaled drawings in plans, elevations, and sections have been the basic tool of the designer's trade since the Renaissance, and the geometrical rules of parallel projections were fa-

mously published in 1799 by Gaspard Monge under the name of descriptive geometry (fig. 1). But seen from a historical perspective, and from today's vantage point, descriptive geometry is another cultural technology typical of a Small Data environment, as descriptive geometry uses parallel projections to compress big 3D objects into a set of small flat drawings, which can be easily recorded, stored, and transmitted on simple sheets of paper. In this instance, the compression of data is also a visible and physical one. No one could store the Seagram Building in reality—it is quite a big building—but many offices could store (and some did, in fact) the batch of drawings necessary to make it, and, if needed, to remake it. Today, however, using digital technologies, we can store not only a huge number of planar drawings, but also full 3D avatars of buildings, on a single memory chip—including all the data we need to simulate that building in virtual reality, or to build it in full. And technologies already exist that allow designers to operate directly in 3D, hence avoiding the mediation of planar drawings and of the geometrical projections underpinning them. In short, if buildings can be entirely notated as informational models in three dimensions from the start, the ways to represent them may change at all times based on need, and in many cases without falling back on plans, elevations, and sections. Descriptive geometry is another cultural technology for data compression already on the way out (and in fact, few schools of architecture still teach it).

The list of cultural technologies that have been with us from time immemorial, but which are being made obsolete by today's Big Data, is already a long one. To take an unusual suspect, the alphabet is a very old and effective technology for data compression: a voice recorder, in fact, that converts an infinite number of sounds into a limited number of signs, which can be easily notated, recorded, and transmitted across space and time. This strategy worked well for centuries, and it still allows us to read transcripts from the voices of famous people we never listened to and who never wrote a line, such as Homer, Socrates, or Jesus Christ. Yet today's technologies allow us to record, transmit, retrieve, and process speech as sound, without converting it into alphabetical signs (for the time being, the machine still does it, unbeknownst to us; but this may change, too). Thus today we can already speak to some machines without using keyboards, and receive answers from machines that vocalize words we no longer need to read. Keyboards used to be our interface of choice to convert the infinite variations of our voice (Big Data) into a short list of standardized signs (Small Data), but this informational bottleneck, typical of Small Data environments, is already being bypassed by today's speech-recognition technologies.

If the prospect of building without drawing frightens many architects, a civilization without writing may appear more than apocalyptic—almost a contradiction in terms. Yet, in purely

informational terms, most technologies of notation (from numerals to Euclidean geometry; from musical scores to the Laban scripts for dancers) are tools we created in order to convert complex, data-rich phenomena into stripped-down and simplified transcriptions that are easier to keep, edit, and forward to others. These transcriptions are less and less necessary today as, thanks to Big Data, we can record, transmit, and manipulate digital avatars that are almost as rich in data as the originals they replace (and far richer in metadata). Of course, no digital replica will ever replace a natural phenomenon in full, as every copy implies some degree of abstraction, hence some data will always be left out or lost in the process. But in practice, once again, it is the tendency that matters, and this tendency has already started to affect today's science, technology, and culture.

Let's take another example—and one well-known one among architects, as it has been at the core of digitally intelligent design for the last twenty years: the calculus-based, digital spline. Calculus, another great invention of baroque mathematics, is the ultimate Small Data technology, as it compresses an infinite number of points into a single short notation, in the format $y = f(x)$. In practice, the script of a function contains all the points we may ever need to draw or produce that line (curve, or, adding one letter, surface) at all possible scales. But let's put ourselves, again, into a Big Data state of mind, and let's assume we can have access to unlimited, zero-cost data storage and

processing power. In that case, we could easily do away with any mathematical notation, and simply record instead a very long, dumb log: the list of the positions in space (X,Y,Z coordinates) of many points of that line—as many as necessary, perhaps a huge number of them (fig. 2). That file will record the individual positions in space of a cluster or cloud of points that may not appear to follow any rule or pattern—any rule or pattern would in fact be of no use, so long as the position of each point is known, measured, and recorded, in two or three dimensions. This is exactly the kind of stuff humans don't like, but computers do well. A long time ago we invented dimensionless Euclidean points and continuous mathematical lines to simplify nature and translate its unruliness into short, simple, elegantly compressed notations: Small Data notations, made to measure for the human mind; notations we could write down, and work with. But today computers do not need any of that any more. Today's digital avantgarde has taken due notice: some digital designers have already discarded the Small Data, calculus-based spline (Bézier's spline), which was so important for the digital style of the 1990s, and have started to use Big Data and computation to engage the messy discreteness of nature as it is, in its pristine, raw state—without the mediation of elegant, streamlined mathematical notations.[4]
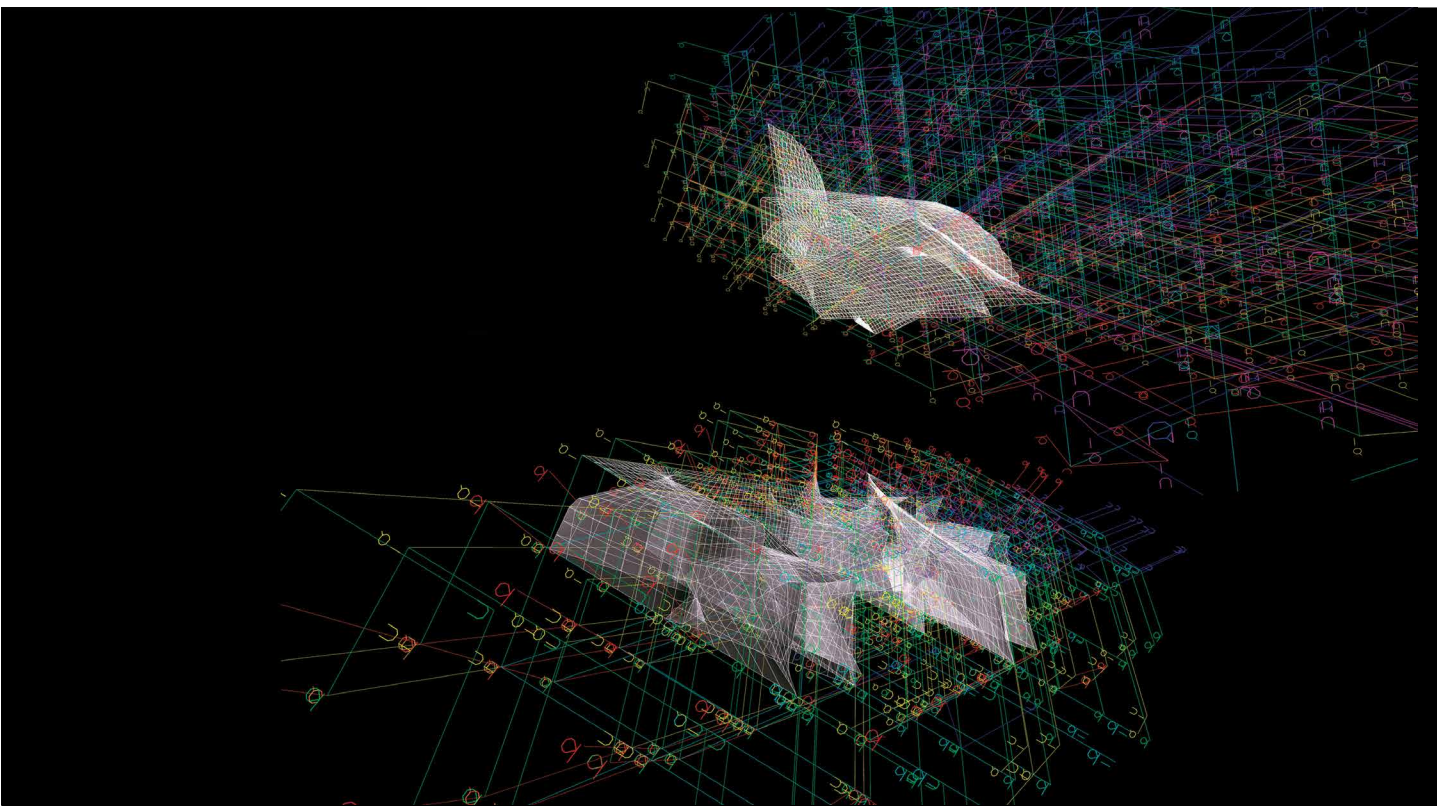
Figure 2: Karl Chu, X Kavya, The Turing Dimension, 2010. Credits: Karl Chu X Phylum project records. Canadian Centre for Architecture. Gift of Karl Chu © Karl Chu.

# Search, Don't Sort: The End of Classical and Modern Science

This new trend in today's post-spline digital style may be discounted as a fad, a quirk, or an accident. It shouldn't be. All major, pervasive changes in our visual environment are signs of a concomitant change in our technical, economic, and scientific paradigms. Indeed, if we look back at our data-starved past from the perspective of our data-opulent present, all the instances just mentioned (and more could be added) suggest that Western science as a whole, from its Greek inception, could be seen today as

a data-compression technology developed over time to cope with a chronic shortage of data storage and processing power. Since the data we could record and retrieve in the past was limited, we learned to extrapolate and generalize patterns from what data we had, and we began to record and transmit condensed and simplified formal notations instead of the data itself. Theories tend to be shorter than the description of most events they apply to, and indeed syllogisms, then equations, then mathematical functions, were, and still are, very effective technologies for data compression. They compress a long list of events that happened in the past into very short scripts, generally in the format of a causal relationship, which we can utilize to describe all other events of the same kind, including

future ones. In his last book, *Discorsi e Dimostrazioni Matematiche*, which had to be smuggled out of Tuscany and printed in a Protestant country to escape the Inquisition's censorship, Galileo reported and illustrated a number of experiments he had made to study how some beams break under load.[5] But we need not repeat any of his experiments, nor any other, to determine how standard beams will break under most standard loads, because, generalizing from Galileo's experiments and many more that followed, we have obtained a handful of very general laws, which all engineers study in school: a few, clean lines of mathematical script, easy to commit to memory, which derive from all the beams that broke in the past, and describe how most beams will break in the future under similar conditions. This is how modern science worked—until now.

For let's imagine, again, that we can collect an almost infinite amount of data, keep it forever, and search it at will at no cost. We could then assume that every one of those experiments—or more generally the experiential breaking of every beam that ever broke—could be notated, measured, and recorded. In that case, for every future event we are trying to predict, we could expect to find and retrieve a precedent, and the account of that past event would allow us to describe the forthcoming one without any mathematical formula, function, or calculation. The spirit of Big Data, if there is one, is probably quite a simple one, and it reads like this: whatever happened before, if it has

been recorded, and if it can be retrieved, will simply happen again, whenever the same conditions reoccur. This is not very different from what Galileo and Newton thought. But Galileo and Newton did not have Big Data; in fact, they often had very little data indeed. Today, instead of calculating predictions based on mathematical laws and formulas, using Big Data we can simply search for a precedent for the case we are trying to predict, and retrieve it from the almost infinite, universal archive of all relevant precedents that ever took place. When that happens, Search will replace the method of modern science in its entirety.

This apparently weird idea is not science fiction. This is already happening, in some muted, embryonic way, in several branches of the natural sciences, and more openly, for example, in weather forecasting. Once again, this may not be either a rational or a palatable fact, but it is a tendency—it is in the air, whether we like to admit it or not. And sure enough, some historians of science have already started to investigate the matter—with perplexity and reservations, as we could expect.[6]

Indeed, from an even more general, philosophical point of view, mathematical abstractions such as the laws of mechanics or of gravitation, for example, or any other grand theory of causation, are not only practical tools of prediction but also, perhaps first and foremost, ways for the human mind to make sense of the world—and some could argue, as many did in the past,

that the laws thus discovered are Laws of Nature, that disclose and unveil inner workings. Conversely, if abstraction and formalization (i.e., most of classical and modern science, in the Aristotelian and Galilean tradition) are seen as merely contingent data-compression technologies, one could argue that in the absence of the technical need to compress data in that particular way, the human mind can find many other ways to relate to, or interpret, nature. Epics, myth, religion, and magic, for example, offer vivid historical examples of alternative, non-scientific methods; and nobody can prove that the human mind is or ever was hardwired for modern experimental science. Many postmodern philosophers, for example, would strongly object to that notion.

This is probably not a coincidence, since the postmodern science of Big Data marks a major shift in the history of the scientific method. Using the Big Data approach to science (i.e., prediction by search and retrieval of precedent, instead of prediction by the transmission of general laws), modern determinism is not abandoned, but employed at a new, granular scale. Western science used to apply causality to bigger and bigger groups, or sets, or classes of events—and the bigger the group, the more powerful, the more elegant, the more universal the law that applied to it. Science, as we knew it, tended toward universal laws, which bear on as many different cases as possible. Today's new science of Big Data is just the opposite: using information retrieval and the search for precedent,

Big Data causality can be applied to smaller and smaller sets, and it works best when the sets it refers to are the smallest. Indeed, the new science of Big Data only works in full when it does not apply to a class or group of events, but only to one, specific, individual case—the one we are looking for. In that too Big Data represents a complete reversal of the classical (Aristotelian, scholastic, and modern) scientific tradition, which always held that individual events cannot be the object of science: most Western science only dealt with what Aristotle called forms (which today we more often call classes, universals, sets, or groups).

In social science and in economics, this novel Big Data granularity means that instead of referring to generic groups, social and economic metrics can and will increasingly relate to specific, individual cases. This points to a brave new world where fixed prices, for example, which were introduced during the industrial revolution, will cease to exist (and famously, this is already happening). Likewise, the cost of medical insurance, calculated as it is today on the basis of actuarial and statistical averages, could become irrelevant, because it will be possible to predict, at the granular level, that some individuals will never have medical expenses, hence they will never need any medical insurance, and some will have too many medical expenses, hence no one will ever sell medical insurance to them. This is a frightening world, because the object of this new science of granular prediction will no longer

Figure 3: **ICD/TKE Research Pavilion2013-2014**, Institute for Computational Design (ICD, Prof. Achim Menges) and Institute of Building Structures and Structural Design (ITKE, Prof. Dr.-Ing. Jan Knippers) at the University Stuttgart. Based on the differentiated trabeculae morphology and the individual fiber arrangements, a double-layered modular system was generated for implementation in an architectural prototype. ©ICD/ITKE Universität Stuttgart.

Figure 4: Correlation of fiber layout and structural morphology in trabeculae. © Dr. Thomas van de Kamp, Prof. Dr. Hartmut Greven | Prof. Oliver Betz, Anne Buhl, University of Tübingen.
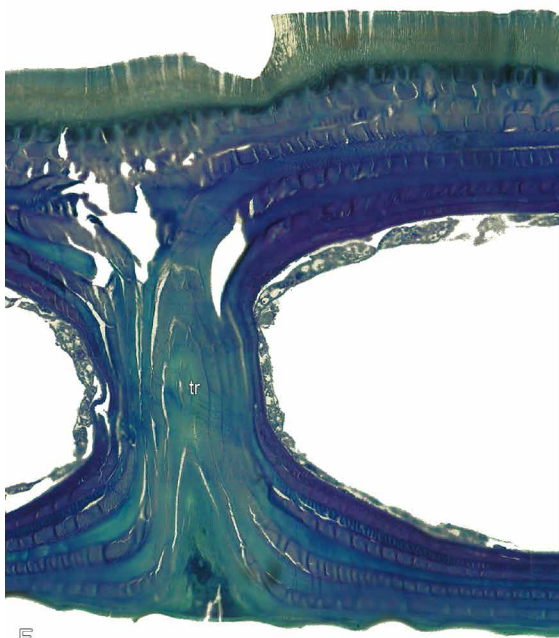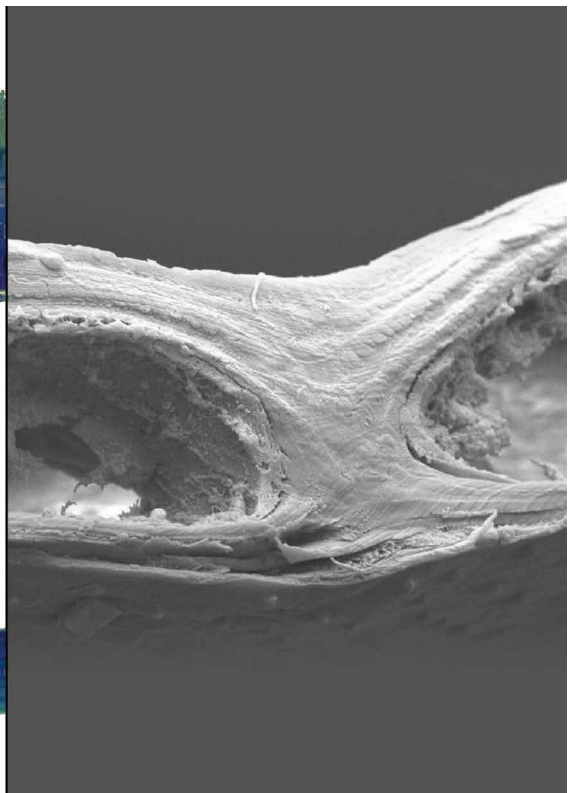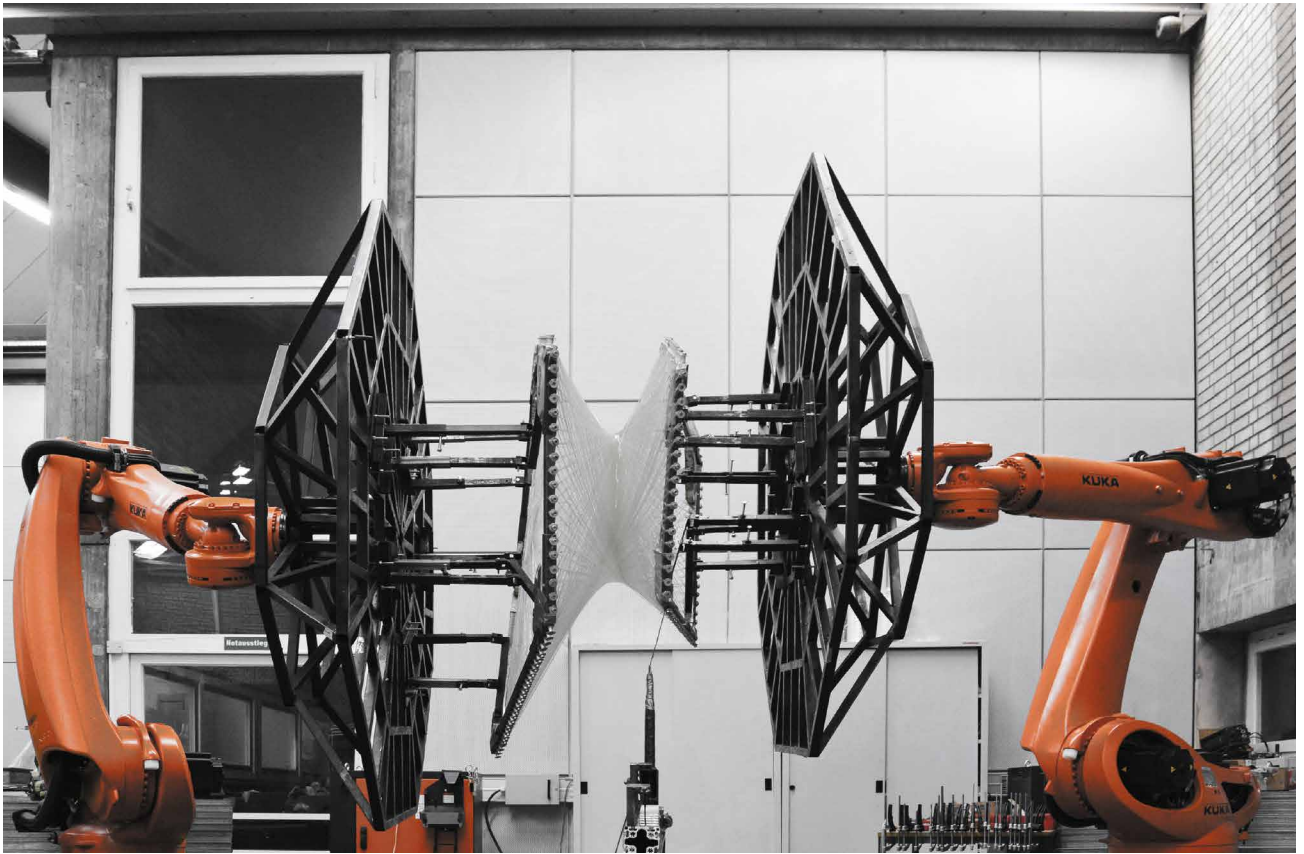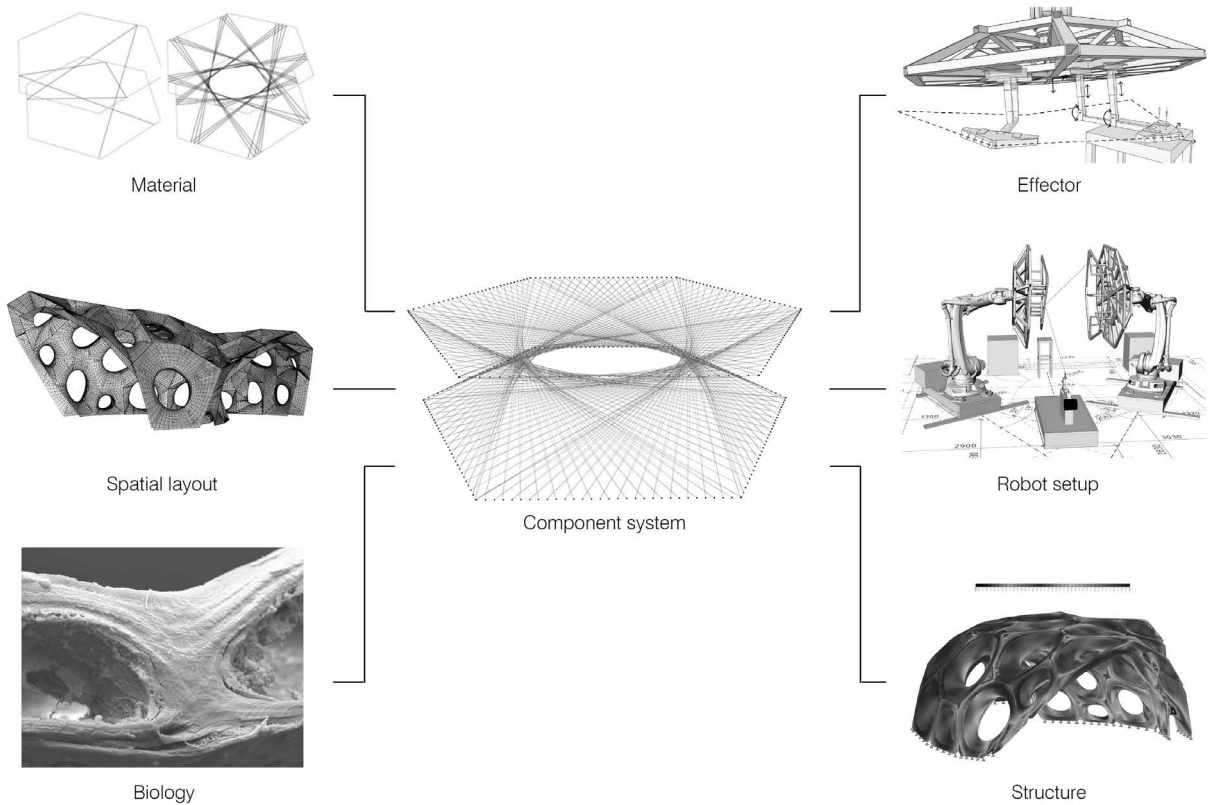
Figure 5: Dual robot fabrication setup: Coreless filament winding. © ICD/ITKE University of Stuttgart.

Figure 6: Integration of multiple process parameters into a component based construction system. © ICD/ITKE University of Stuttgart.



Material

Effector

Spatial layout

Robot setup

Component system

Biology

Structure

be a statistical abstraction—it will be each of us, individually. This may be problematic from a philosophical and religious point of view, as it challenges traditional ideas of determinism and free will; but in more practical terms, it is also simply incompatible with most principles of a liberal society and of a market economy in the traditional, modern sense of both terms.

In the field of natural sciences, however, the picture is quite different, and apparently less frightening. Following the old (i.e., the "modern") scientific method, natural sciences too used to proceed by generalization and abstraction, applying more and more general formulas to larger and larger swaths of the natural world. To the contrary, using the new method of granular retrieval of precedent, we are no longer limited to predicting vast and general patterns— we can try and predict smaller and smaller events, up the most singular ones. As recent works by Neri Oxman, Achim Menges, and others have proven, we can now design structural materials at minuscule, almost molecular scales, or quantify and take into account the infinite, minute, and accidental variations embedded in all natural materials (fig. 3-6).[7]

This runs counter to the method of modern science, which traditionally assimilated all materials, natural and artificial alike, to homogeneous chunks of continuous matter: for the last two centuries the main mathematical tool at our disposal to describe structural and material deformations was differential calculus, which is a mathematics of continuity, and abhors singularities; to allow for mathematical modeling (i.e., a quantitative prediction of their behavior), new industrial materials were designed to be isotropic and continuous, and natural materials were doctored, processed, and tinkered with to achieve some degree of homogeneity.

To the contrary, using the granularity of Big Data, we may now model the structural behavior of each individual part in a hypercomplex, irregular, and discontinuous 3D mesh, including the behavior of the one part we are interested in— that which will fail, one day. Used this way, the new science of granular prediction does not constrain but liberates, and almost animates, inorganic matter.

# Search, Don't Tell: The End of Classical and Modern History

Since data scarcity has been a universal human condition across all ages, cultures, and civilizations, we can expect to find similar strategies of data compression embedded in most, if not all, cultural technologies we have been familiar with to this day. Historiography, or the writing of history, codified as an academic discipline and cultural practice in the course of the nineteenth century, is no exception.

Like the modern scientist, the modern historiographer must infer a theory (in the case of history, more often an argument or a story) from a vast archive of findings. This data is not reported as such (even though today facts and sources are often listed or referred to in footnotes), but it is subsumed and transfigured, as it were, in a larger narrative—namely, a history—that derives from the original findings, but encompasses and describes them in more general terms. In this sense the historiographer, like a bard or ancestral storyteller, must condense and distill an accumulation of accidental experiences into one streamlined sequence or story, following a linear plot that is easier to remember and to recount, while most of the factual events that inspired it are destined to remain anecdotal—i.e., literally, unsaid. Halfway between the storyteller's plot and the scientist's theory, the historiographer's narration, or history, weaves endless anecdotes into one meaningful narrative.[8] This narrative, once again, functions as a lossy data-compression technology: only the story thus construed will be recorded and transmitted and will bear and convey memories, wisdom, or meaning, whereas most of the individual events, experiences, or (in the Aristotelian sense of the term) accidents that inspired it will be discarded and forgotten.

Yet, as Walter Benjamin had already intuited, today's increasingly abundant dissemination of raw information goes against this ancestral strategy of story-building and story-telling.[9]

Let's imagine, once again pushing the argument to its limits, that a universal archive of historical data may be collected, recorded, transmitted, and searched at will, by all and forever. The term "historical" would become ipso facto obsolete, as all facts must have occurred at some point in time in order to have been recorded, hence all data in storage would be "historical," and none more so than any other. And since Google has already proven that no two searches are the same, every search in this universal archive would likely yield new results—based on user preference, context, endless more-or-less secret parameters, and the sheer complexity and whim of search algorithms. Consequently, at that point no "narrative," theory, story, or sequence would be stronger than any other; in fact no narrative, theory, sequence, or story would even be needed or warranted any more. Only the data would speak—forever, and whenever asked, never mind by whom, and every time anew.

Again, it is easy to dismiss this Big Data scenario (which, it will be noted, is structurally similar to the postscientific, prediction-by-retrieval paradigm I outlined earlier) as a sci-fi nightmare. Yet, once again, signs of this impending change can already be seen in today's technology and culture, and they are seeping through contemporary social practices. Take this example, which will sound familiar to many scholars of my generation: for all undergraduates studying architectural history in Italy (and elsewhere, for that matter) in the late 1970s or early

'80s, the architectural history survey was basically a book, sometimes two, outlining a much simplified, teleological and ideological narrative of the rise of the modern movement in architecture (in Pevsner's and Giedion's historiographical tradition, that was the Hegelian and Marxian story of a linear rise to culmination, with no fall ever to ensue). Our textbooks (no names mentioned) contained a limited selection of small, and often very poor black-and-white pictures of the buildings under discussion, and these pictures, in most cases, were the only available evidence of buildings that few students, and indeed not many of our teachers, had ever seen. This is why we went to class, when we could: not so much to hear but to see. Giovanni Klaus Koenig's lectures were popular across the whole university of Florence (and beyond) not only because of Koenig's unparalleled talent as a jocular storyteller, but also because of the color slides he showed, which he had taken while traveling by car to Germany, Austria, and Switzerland (therefore no images of French or American buildings, for example, were ever shown). Most of the learning we could glean in such a technocultural environment was, and could not have been anything other than, a narrative: a story, or a theory, which we got to know much better than any of those famous buildings upon which those stories were supposedly predicated.

As for the buildings themselves, some we could visit when traveling, and some we would get a glimpse of, somehow, through a handful of color photographs in the relatively few books we could peruse at university libraries or buy in bookshops. A quarter of a century after Malraux's *Musée Imaginaire*, even the most famous buildings of the twentieth century were still known exclusively through a very limited repertoire of authorial pictures, often due to some well-known photographers working in collaboration with the architects. Before I first traveled to Berlin as a student, I knew Ezra Stoller's photographs more than Mies van der Rohe's buildings.

Compare that situation—which was the norm throughout the age of printing and of modern mechanical technologies—to today's wealth of visual and verbal documentation, available at the click of a mouse, by tapping on a touch-screen, or—as I just did—by saying "Mies van der Rohe" to my smartphone. One generation ago, the same scant data was imparted to all. Today, information is so abundant and easily searchable that each user can find her or his own. But due to the largely unauthorial, raw or crowdsourced nature of most of this wealth of information, each person doing the same search will likely come up with slightly different results, and sometimes with conflicting or incompatible information. That is indeed the way Big Data works, for scientists no less than for students or for the general public: Big Data is useful and usable only on average, and in the aggregate.

Failing that, each enduser will construct her or his own argument based on a random or arbitrary selection from

an extraordinary array of data, and each selection will likely be different from all others. Each narrative or argument thus put together will therefore tend to idiosyncrasy and ephemerality. Anyone who has tried to teach a research seminar in the traditional way (i.e. expounding a sequential argument) in front of a group of doctoral students busily ferreting out odd happenstances, Photoshopped images, and wrong information from their tablets in real time will be familiar with this predicament. This does not mean that a thousand anonymous pictures on Instagram and a promenade through Google Earth are worth less than a single shot by Iwan Baan—in fact, in statistical terms, the opposite is true. But this does mean that many cultural habits we used to take for granted were in fact the accidental fallout of data-skimping, and are already incompatible with the data-rich environment we live in. Whether we like it or not, when an infinite amount of facts are equally available for anyone's perusal, search, and retrieval, we may no longer need theories, stories, histories, or narratives to condense or distill data, and to present them in a linear, clean, and memorable array. Again, one may argue that we will always need theories and stories for a number of other reasons, but—as mentioned earlier—that is difficult to prove.

So it would appear that many antimodern and postmodern ideological invocations or vaticinations, from Nietzsche's "eternal recurrence" and Lyotard's "fragmentation of master narratives" to Baudrillard's or Fukuyama's "end of history," to name a few, all came, in retrospect, a bit too early—but all may soon be singularly vindicated by technological change.[10] What ideology could not accomplish in the twentieth century, technology is making inevitable in the twenty-first. If Search is the new science, *Big Data* is the new history. But not the history we once knew.

# Notes

[1] This article was originally commissioned by the editors of *Perspecta 48: Amnesia* (2015: 48-60), a publication of the Yale School of Architecture, and I am grateful in particular to Aaron Dresben and Andrea Leung for their insight, the editorial assistance they offered, and for researching and choosing the illustrations that accompanied the article when it was first published. It is republished here by the permission of the editors and of the Yale School of Architecture. Some of the topics I anticipated here are developed in my book, *The Second Digital Turn: Design Beyond Intelligence* (MIT Press, September 2017), to which the reader is also referred for a more recent bibliography.

[2] On the origin and different meanings of the expression "Big Data", see Victor-Mayer Schönberger and Kenneth Cukier, *Big Data: A Revolution that Will Transform How We Live, Work, and Think* (Boston and New York: Houghton Mifflin Harcourt, 2013), 6 and footnotes.

[3] Pierre-Simon de Laplace, *Exposition du système du monde* (Paris: Imprimerie du Cercle-Social, IV–VI [1796-98]), vol. II, 5, IV, p. 266. ("[Kepler...] eut dans ses dernières années, l'avantage de voir naître et de profiter de la découverte des logarythmes, artifice admirable, dû à Neper, baron écossais; et qui, réduisant à quelques heures, le travail de plusieurs mois, double, si l'on peut ansi dire, la vie des astronomes, et leur épargne les erreurs et les dégoûts inséparables des longs calculs ; invention d'autant plus satisfaisante

pour l'esprit humain, qu'il l'a tirée en entier, de son propre fonds. Dans les arts, l'homme emploie les matériaux et les forces de la nature, pour accroître sa puissance; mais ici, tout est son ouvrage.")

[4]  I discussed this in "Breaking the Curve: Big Data and Digital Design," *Artforum* 52, no. 6 (2014): 168–73.

[5]  Galileo Galilei, *Discorsi e Dimostrazioni Matematiche intorno* à *due nuove scienze, attinenti alla mecanica e i movimenti locali* (Leiden: Elzevir, 1638), 116–33. In July 2008, a groundbreaking article by Chris Anderson first argued for a scientific revolution brought about by Big Data ("The End of Theory," *Wired* 7 [2008], 108–9). Although that issue of *Wired* was titled "The End of Science," the other essays in the "Feature" section of the magazine did little to corroborate Anderson's vivid arguments. The main point in Anderson's article was that ubiquitous data collection and randomized data mining would enable researchers to discover unsuspected correlations between series of events, and to predict future events without any understanding of their causes (hence without any need for scientific theories). A debate followed, and Anderson retracted some of his conclusions (Schönberger and Cukier, 2013, 70–72 and footnotes). From an epistemological point of view, however, what was meant by "correlation" in that debate did not differ from the modern notion of causality, other than in the practicalities of the collection of much bigger sets of data, and in today's much faster technologies for data processing. Both classical causation and today's computational "correlation" posit quantitative, cause-to-effect relationships between phenomena; and at the beginning of the scientific enquiry, both the old (manual) way and today's computational way need some hypotheses to select sets of data among which even unexpected correlations may emerge. Evidently, today's computational processes make the testing of any such hypotheses much faster and more effective, but the methodological and qualitative changes that would follow from such faster feedback loops between hypotheses and verification were not part of that discussion. A somewhat similar but more promising debate is now taking place in some branches of applied technologies, such as structural engineering. See Mario Carpo, "The New Science of Form Searching," forthcoming in "Material Synthesis: Fusing the Physical and the Computational," ed. Achim Menges, special issue, *AD: Architectural Design* 85 (2015): 5.

[6]  See D. Napoletani, M. Panza, and D. C. Struppa, "Agnostic Science: Towards a Philosophy of Data

Analysis," *Foundations of Science* 16 (2011): 1, 1–20. As a search always starts with, and aims at, one individual event, the science of search is essentially a science of singularities; but the result of each search is always a cloud of many events, which must be compounded, averaged, and aggregated, using statistical tools. Thus, there are no limits to the level of "precision" of a search (a lower level of precision, or less intension, will generate more hits, or a larger extension in the definition of the set). On this aspect of Aristotelian science, see Carlo Diano, *Forma e evento. Principi per una interpretazione del mondo greco (*Venice: Neri Pozza, 1952). The rejection of modern science as a science of universals is central to the postmodern philosophy of Gilles Deleuze and Félix Guattari. In *Milles Plateaux*, in particular, Deleuze and Guattari opposed the "royal science" of modern science, based on discretization ("striated space") to the "smooth space" of "nomad sciences," based on "nonmetric, acentered, rhizomatic multiplicities that occupy space without counting it and can be explored only by legwork," which "seize and determine singularities in the matter, instead of constituting a general form... they effect individuations through events or haecceities, not through the object as a compound of matter and form." Deleuze and Guattari saw the model of nomad sciences in the artisan lore of medieval master builders, i.e. in the past, before the rise of modern science; and they had no foreboding of the then nascent technologies that would inspire digital makers one generation later. See Gilles Deleuze and Félix Guattari, *A Thousand Plateaus: Capitalism and Schizophrenia*, trans. B. Massumi (London and New York: Continuum, 2004), 406–9 and 450–51. (First published in French as *Milles Plateaux* [Paris: Les Editions du Minuit, 1980]).

[7]  See Mario Carpo, "Micromanaging Messiness: Pricing, and the Costs of a Digital Nonstandard Society," in "Money," *Perspecta* 47 (2014): 219–26. See Neri Oxman, "Programming Matter," in "Material Computation: Higher Integration in Morphogenetic Design," ed. Achim Menges, special issue, *AD: Architectural Design* 82 (2012): 2, 88–95, on variable property materials; Achim Menges, "Material Resourcefulness: Activating Material Information in Computational Design," ibid., 2, 34–43, on non-standard structural components in natural wood. This vindicates the premonitions of Ilya Prigogine, another postmodern thinker whose ideas were a powerful source of inspiration for the first generation

of digital innovators in the 1990s. See in particular Ilya Prigogine and Isabelle Stengers, *Order Out of Chaos: Man's New Dialogue with Nature* (New York: Bantham Books, 1984). (First published in French as *La Nouvelle Alliance: métamorphose de la science* [Paris: Gallimard, 1979]).

[8] Walter Benjamin, "The Storyteller: Reflections on the Works of Nikolai Leskov," in *Illuminations: Essays and Reflections*, trans. Harry Zohn, ed. Hannah Arendt (New York: Schocken Books, 1968), 83–109. (First published as "Der Erzähler: Betrachtungen zum Werk Nikolai Lesskows," in *Orient und Okzident* [City: Publisher, 1936]). However, Benjamin considers the ancestral storyteller and the oral chronicler as the conveyors of raw data, and sees only the modern novel and historiography as abstract, simplified linear narratives that are construed independently from the events on which they are based and from which they

derive. After the works of Marshall McLuhan and particularly of Walter Ong on the cultures of orality, it is easier today to see the bard's/storyteller's recitals as tools of abstraction and memory devices.

[9] See note 7.

[10] Nietzsche's first mention of "eternal recurrence" is in aphorism 341 of *The Gay Science* (*Die fröhliche Wissenschaft,* 1882–87). Lyotard spoke of the "décomposition des grand Récits," or "métarécits": Jean-François Lyotard, *La condition postmoderne* (Paris: Les Éditions de Minuit, 1979), 31. The "end of history" may have been first proclaimed by Jean Baudrillard, *Simulacres et Simulations* (Paris: Galilée, 1981), 62–76 (see in particular p. 70: "l'histoire est notre référentiel perdu, c'est-à-dire notre mythe"). Francis Fukuyama, *The End of History and the Last Man* (New York: Free Press, 1992). See also Fukuyama, "The End of History?" *The National Interest* 16 (Summer 1989): 3–18.

**Mario Carpo** is Reyner Banham Professor of Architectural History and Theory at The Bartlett, University College London.

Carpo is internationally known for his teachings and research on the history of architectural theory and the history of cultural technologies, with focus on the classical tradition and on contemporary digital design theory. His main publications are "The Digital Turn in Architecture, 1992-2012" (Chichester: Wiley, 2012), "The Alphabet and the Algorithm" (Cambridge, MA: The MIT Press, 2011, also translated into other languages), "Architecture in the Age of Printing (Cambridge, MA: The MIT Press, 2001), and "The Second Digital Turn. Design Beyond Intelligence" (Cambridge, MA: The MIT Press, 2017).

Correspondence e-mail: m.carpo@ucl.ac.uk