Automation Takes Command

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INTRODUCTION

This paper departs from a few assumptions about technology in architecture that derive from the history and philosophy of technology. The first is that every technology is social before it is technical or physical.[1] Technical development is first an expression of an immaterial need or desire, and only later becomes material and technical. Secondly, when a technology does become physical, it is not a benign reserve of technical solutions to social, ecological, or fabrication problems but rather produces its own risks and problems as a constitutive fact of that technology. All technologies contain some form of risk.[2] Third, any technology is not new. If we will understand technology at all, we will begin to see it as an uninterrupted and ubiquitous practice.[3] All technologies have a long period of social, cultural, technical, and practical preparation. In our mythical paradigm of progress and technical mastery, terms such as "new" are merely rhetorical escalations. Finally, every technology is principally undetermined until it situated within the broader economic, social, and cultural assembly that presupposes and engenders that technology.[4] We will know very little about the capabilities and culpabilities of technology if we only study a technology in terms of its technical performance in building production. These four principles orient an approach to technology that aims at a broader understanding of technical effects, as evidenced in the case of digital fabrication techniques in architecture.

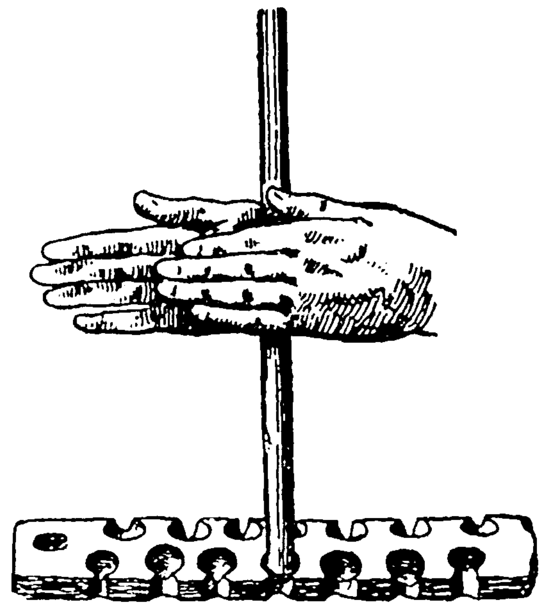

Figure 1. Fire drill

NUMERICAL CONTROL

When you examine the infrastructure and tools of the most common digital fabrication appliances, you quickly realize that most of its apparatus is familiar if not archaic. Take for instance, the two most common cutting mechanisms in CAD/CAM technologies: the rapidly rotating router bit and the laser. The router bit is merely a refined application of the archaic partial rotary motion tools such as the fire-drill, bow-drill, and pump-drill used throughout archaic world as boring and cutting tools.[5] (figure 1) For the part of the laser, the application of concentrated energy to cut by heating and thereby severing molecular bonds is but a refined form of the fire drill and fire plough that cut with similar but less concentrated applications of heat and friction.[6] Now these technologies obviously have undergone massive refinement especially through the mechanical and electronic paradigms of the 19th and 20th centuries, but their operative principles remain in tact.

What is 'new,' and thus the source of our extravagant expectations for digital fabrication, is the control of a cutting bit along a path, no longer controlled by the extremely sensitive neurological-muscular apparatus of a human technician but now by a computer. Numerical Control is the technique that enables CNC operations, parametric design techniques, and the management of design information as in the case of BIM's and "mass customization." Numerical Control is the primary technique in digital fabrication technologies. Numerical Control was the term developed by the Air Force after World War II in their search for an elaborate manufacturing system capable of producing primarily repetitive and occasionally complex components for warplanes and weapons systems.[7] While this history of military enterprise in the 1950's is important, it is important to establish first the cultural preparation of Numerical Control in architecture and our adjacent disciplines. A brief history of Numerical Control will establish where, when and how the concept and implementation of Numerical Control derives. It is not new. It is in fact a deep and pervasive impulse in all that we call modern.

What was the effect of the introduction of Numerical Control into Western technics?

The history of Numerical Control is a history of a technique that is used most effectively to *regularize, routinize, and quantify* that which is otherwise is qualitative. There is no better term to describe impetus behind the development of western technics, western capitalism, the bureaucratic command and control apparatus, and our current paradigm as a risk society than the term *Numerical Control*.[8] To be sure, Numerical Control is a technical concept that extends well beyond our nascent digital fabrication practices in architecture.

While there were many notable Numerical Control devices throughout the prelapsarian world that dampened an erratic and harsh prehistoric life, it was in the monasteries of the west that *Numerical Control* explicitly and officially emerged as a consistent technique of regularization and routinization.[9] The Benedictine monasteries at the beginning of the last millennium synchronized the liturgical hours with a bell tower mechanism, creating a mechanized machine of time. The monastery regularized the spatial and temporal behavior of the monks but in doing so also fundamentally transformed our experience of duration. Our physiological systems were no longer synchronized to the rhythms of the sun, seasons, and free morphogenesis but would rather be mechanized by numbers. These clocks changed everything in the west by initiating an endless succession of quantitative methods whose fundamental ambition was to coordinate human production of all sorts, a constant theme of Numerical Control.[10]

Numerical Control migrated from the Benedictine monastery clock and bell mechanism into the market centers of European towns to regularize and control trade. As the emerging capital model of trade physically shaped Europe, the incorporation of double entry book keeping was the next significant application of Numerical Control at this time. Double entry bookkeeping regularized the financial transactions and standardized a system for controlling the numbers involved in monetary transactions. Soon after this, the laws of perspective, cartography, and the mathematics of planetary motion, would do for space what the clock had done for time in terms of regularization and quantification. In architecture, the laws of perspective, the quantification of the orders, and the deployment of grids and regulating lines each relate to this history of Numerical Control.

As our infatuation in the west with Numerical Control proceeded into the industrial revolution, the famous Jacquard loom with its punched card programs for the warp and weft is emblematic of an era of proto-cybernetic machines. In addition to such machines, the development of Numerical Control for material science was equally important. The early efforts to quantify materials into a science were not of civilian origin but rather the product of military enterprise. In the 19th century US Army Ordnance Department our understanding of matter itself slowly becomes increasingly engineered, that is controlled by numbers.

Following the narrow victory of the War of 1812, The US Army Ordnance Department redirected its efforts from merely storing munitions to developing completely consistent fabrication processes *and materials* that would produce interchangeable components for their firearms. The Ordnance Department produced master jigs that could control the production of weaponry in their factories throughout the United States. This approach regularized the materials and methods of geographically distinct production through an elaborate command and control style bureaucracy.

The Ordnance Department production methods prepared the post World War II development of Computer Numerical Control (CNC) in a variety of important ways. First, the Ordnance Department was the original production system regularized by a broad bureaucratic organization controlled by a network of unified materials, patterns (jigs), and communication (telegraph and railroad).[11] Consequently, by the turn of the century, in was these 19th century arms dealers that would go on to develop and perfect what is known as 'American System of Management and Manufacture' or more commonly as scientific management-the most common application being the familiar Taylorized assembly line.[12] Second, the metallurgy of the cannon, the rifle, and the conoidal bullet systematized material science in the United States. As such, the Ordnance department initiated much of engineering design and training in the United States as we now practice it.[13] This engineering research in part engendered the innovative metallurgical architectural practices of James Bogardus and William Le Baron Jenney. Many of the interesting architectural developments that shaped the later 19th and early twentieth centuries relate to the material research in Ordnance department. Third, the switch to standardized production in the Ordnance factories resulted in significant labor disputes that resulted in abandoning the standardized production in its Maryland facility. Finally, the funding structure of the Ordnance Department was the first expression of a permanent war economy. In this unique economy, research, development, and trade are not related to the market but rather to massive defense contracts.[14] The military enterprise concept of permanent war for permanent peace dominated the production of new knowledge and technology throughout the twentieth century in the United States and ultimately engendered *digital fabrication*. The notion of permanent war for permanent peace involves a massive defense expenditure and, as was demonstrated in WWII, battles were won and lost as much in offices and the factories as much as the theater of battle.[15] What is more interesting to note is that these advancements from the Ordnance department were produced in and designed for an economic context that is unrelated to the market economy in which architects practice. If we are to understand the technologies and techniques that emerged from the 19th century at all as preparation for digital fabrication, we must acknowledge this economic condition and its implications. The US Army Ordnance department in the 19th century was a mechanical rehearsal for the development of electronic Numerical Control techniques and technologies in material production that occurred in the 1950's in the United States.

In the escalating the arms race of the cold War, The Air Force developed a set of specifications for a manufacturing process that required the consistent production of machined components for use in fighter planes and other weapon systems.[16] Lucrative Department of Defense contracts sponsored the research and development program. Initially the MIT Servomechanism Lab, along with a commercial helicopter rotary blade manufacturer, developed the Numerical Control System that is the basis for contemporary CAD and CAM systems.[17] This hardware and software system had the following notable developments: the use of the first computer aided drafting program, the first intercontinental-networked design and production practice, and of course the first numerically controlled milling machines.

The primary objective of this Air Force initiative was to automate the production process. The system was perfectly rational to the Air Force. Interchangeable modules designed in one location and then data tapes sent to another or any other for production, an electronic application of the mechanical jig-based system of the Ordnance Department a century before. This system with its top-only hierarchy was specified rather than other Numerical Control systems that still relied upon the intelligence of the technician while automating certain aspects of a task.[18] As a dream of the fully automated factory, the whole system aimed only at the perfect uniformity and repetition of machined parts. However, to do so, the production process eliminated all variables, from the material to the human. Numerically controlled machines replaced human machinists. The Air Force dreamt of fully automated factory floors, producing perfect, complex components around the clock. This system famously claimed to have shortened the loop between design and production. Management communicated directly with and therefore commanded the machine. This conception of the technology-a neutral reserve of technical capabilities and no conception of technical culpabilities remains in active the paradigm of digital fabrication in architecture today.

Euphoric pronouncements of the capabilities and the unspoken culpabilities of Numerical Control characterized the Air Force's Numerical Control program. Similar pronouncements are the source for our extravagant and hubristic expectations for the building industry. Numerical Control is just that: it is merely a set of techniques for controlling numbers. However, Numerical Control does not control the tyrannical and oppressive cruelty that uncritical practices engender in the numerically controlled modes of advanced capitalism.[19] Numerical Control does not manage its own social effects as it automates production. In this way, if any technology is social before it is technical, this brief history of Numerical Control is simultaneously a history of social relations and social construction. The technology transfer concept, in which military technologies such as the computer, radar, the jet engine, the transistor, and the federal highway system, transfer from military enterprise into more or less benign and beneficial civilian usage, is now a well-documented process. However, in all these cases, military technologies are not the only effects transferred in the process. Numerical Control is no exception. Technology transfer also transfers a set of inseparable social effects. These effects are as real as any CNC milled object. Therefore, an enormous yet unspoken social project is implicit in the arguments for digital fabrication and Numerical Control. The current literature on digital fabrication exaggerates the possibilities and capabilities of digital fabrication and numeric control while grossly underestimating the confluence of the social and the technical in forces that shape the history of technology.

One such confluence is the repeated historical relationship between Numerical Control implementation and urbanism. Alongside this history of digital fabrication runs a parallel history of labor and production. In the period sketched out above, you can see labor change from human production to tool production and then from the tool to the program, a process which aims to automate machine production with minimal human interaction. Directly associated with this technical progression is a digression in the required knowledge, skill and practice required by human labor. Most often, this diminishes the value and the wage of labor itself. Numerical Control routinely devalues human judgment, skill, self-reliance, initiative, and creativity.[20] The literature of digital fabrication will no doubt familiarize you with the capabilities of digital fabrication technologies.[21] Rarely, if ever, do they familiarize you with the culpabilities of digital fabrication technologies. They make no mention of the atrophy and depletion of human skill in digital design and fabrication.[22] Nor do they make no any plan for the dislocation and displacement of work that results in structural unemployment, an effect clearly felt in the late seventies and early eighties when factory production in the automotive industry transferred to automated production that sunk much of the upper Midwest into deep economic and skill depression.

In the case of the automotive industry's switch to digital fabrication-as in the case of the US Navy's mandate of containerization in the fifties that sacked the labor of American harbors and the US Army's Ordnance Department's mandate for mass-interchangeable production in the 19th century-the promoters of these technologies promise that these new practices will in balance produce more jobs than they eliminate. Yet in every case, labor suffers and we continue choose the economics and urbanism of structural unemployment when we choose an enthusiastic yet unstudied application of Numerical Control. Why is this type of structural unemployment implicit in the arguments for Numerical Control in the building industry, not of interest to architects and urbanists? Why design systems of production that waste, eliminate, and annihilate knowledge and skill as much as they promise to produce?

One repeated answer that with digital fabrication one can shorten the process, or even close the loop of design and production. To do so, such positions recycle the image of the master builder.[23] It is perhaps tempting to restore to the architect the romantic image of the master builder as practice becomes increasingly abstract and removed. However, architects do not build buildings and are not master builders. They rely heavily upon the trades to advance knowledge about the appropriate products, materials, techniques, and detailing that guide decisions about design. Architects need the accumulated intelligence inherent in the physical side of the building industry. Further, the misplaced concreteness of romantic master builder distracts the architect as they ignore other, actual effects of digital fabrication.

The system of Numerically Controlled fabrication specified by the Air Force and subsequently transferred to civilian use depends upon an unreal uniformity of conditions for it to work at all. Even when it has worked, it raised as many social and economic problems as it solved. When it did not work, the effects of Numerical Control were devastating on all fronts.[24] Yet there is no account of these problems in the digital fabrication literature in architecture.

A recurrent fallacy in the history of Numerical Control is that digital fabrication will improve the very production of architecture and the building industry.[25] Such arguments point to developments in other industries such the aerospace or ship building industries, and ask why architecture has not developed production techniques in parallel progressions. The primary answer is simple and powerful: architecture engages a vastly different market structure. In every instance since the industrial revolution, the techniques that have altered these other forms of Numerical Control fabrication have done so outside the market economy in which architects practice. The Army Ordnance Department, the US Navy's attempt at assembly line production during WWI with Henry Ford, the US Air force CNC program, and the NASA space exploration program each relied on immense funding from the US Government, thereby placing it outside the market economy in which architects typically practice.[26] Numerical Control was developed, and will be optimized, in contexts of massive capital investment. Such investment is not commonly possible within our market economy but rather only possible with heavy government subsidies as in the case of our military industrial complex. It is unlikely that architecture will see the scale of funding required to broadly transform its production techniques.

There is another fundamental difference between the buildings, boats and airplanes that is hard to ignore when you think about the logistics of automated production. The designs and production methods of the aerospace and ship building industry rely upon a simple and very elegant principle: despite their great weight, planes and boats float. If their design and production is successful, their products simply float away from the factory. Nearly all buildings have a radically different operating principle: to sit on specific sites for specific durations.

As opposed to the inevitable architectural specificity due to building codes, unknown site constraints and climate factors, these industries direct their federal subsidies to the capital-intensive infrastructure that is required to produce dozens or hundreds of the same plane whereas architects inevitably aim to make customized solutions for distinct sites. It seems that the repetitive effects of the Numerical Control procedures will come to characterize digital fabrication in general because the historical assemblage of regularization techniques that presupposes it is infinitely stronger than the fragile versions of a few boutique architects attempting to tap into this assemblage, especially because they so little effort to understand it. Those who derive the most benefit from the effects of routinization and management of numbers will most effectively employ digital fabrication. Numerical Control is not about customization or mass customization but thoroughly about regularity and uniformity-which are far more powerful and profitable techniques than customization. The only thing that looks more like a mass-customized, prefabricated house is another mass-customized, prefabricated house. There is a reason for this repetition: efficiency. However, why will these efficiencies promoted in the digital fabrication literature not in turn have the effect of broadly lowering yet again the economic expectations of architectural production? Will qualities not once again slip away to quantities? Do we really want to argue for less yet again as a profession?

Despite the unstudied appropriation of Numerical Control in architecture, there are exceptions that strategically use Numerical Control techniques in a minor way to achieve large-scale effects. These practices are not dominated by Numerical Control and the ambition to 'revolutionize' the building industry but rather use it for their own productive ends.

Two practices and projects illustrate a deeper engagement with minor applications of digital fabrication.

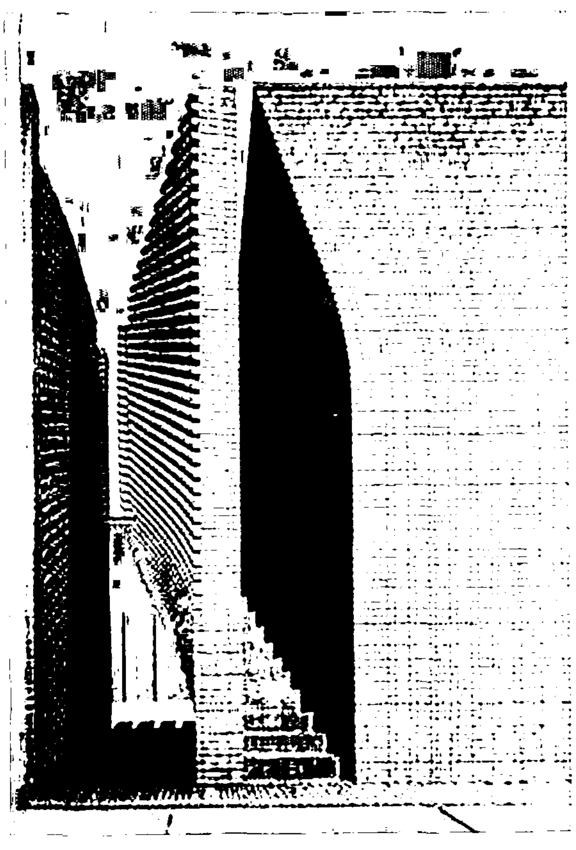

Figure 2. Office DA. Raking masonry wall.

The first project that comes to mind is the Tonxgxian Gatehouse in Beijing by Office DA. (figure 2) The project is familiar amongst the architects' work in its preoccupation with unlikely forms derived from basic but exhausted tectonics. What is unique to this project is the particular way in which digital fabrication intersects a low-tech building material and relatively low tech building crew to yield an advanced project. Here the Numerical Control infrastructure was deployed in a minor way to cut templates that facilitated the raking and corbelling of the masonry to fit particular curves.

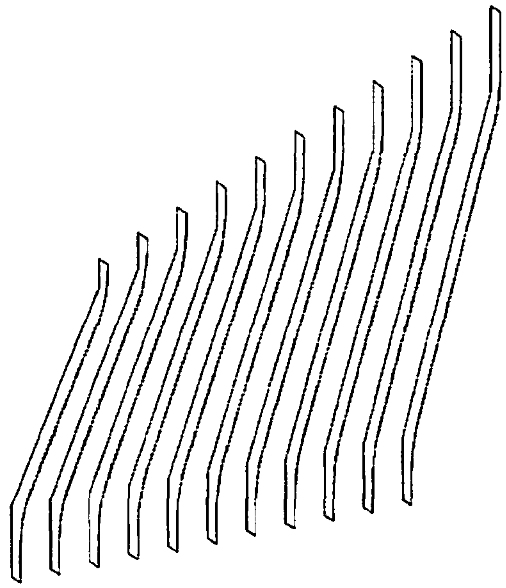

Figure 3. Office DA templates.

The templates and the resultant curves are mildly interesting, but the fact that the designers were engaged with and thinking through the implications of the particular building crew (their abilities and liabilities) while generating and modifying the form of this project is very interesting. The labor condition in this project directs the use of digital fabrication rather than aiming to eliminate that labor condition. This project also demonstrates for this crew that other possibilities and techniques exist for masonry assembly, thereby expanding the crew's repertoire and abilities. It is the knowledge expanding role digital fabrication plays in this project's dialectic of architectural intelligence and labor intelligence that the truly novel aspect of this project.

The second practice is a series of projects that Gilles Perraudin has completed in Southern France. (figure 3) In this practice, Perraudin also deploys digital fabrication in a minor role. Instead of forging radical shapes with traditional labor, he forges a complex relationship between energy, material, and climate with a very simple shape. In a series of related projects, Perraudin extracts stone blocks from an adjacent and otherwise inactive stone quarry. He then water jet cuts the stone to precise repetitive blocks. The blocks' great weight and ultra-flat surfaces allow mortar free assembly. The whole wall assembly is up in a few days. The minimal doors, glazing and roof are installed shortly thereafter. The block's thermal mass modulates interior comfort with no other mechanical devices. In the case of this project, digital fabrication engenders a type of construction that deploys archaic but intelligent material knowledge. In these projects, digital fabrication is minor but essential because it is what allows the dry construction of an extremely durable and thus embodied-energy building.

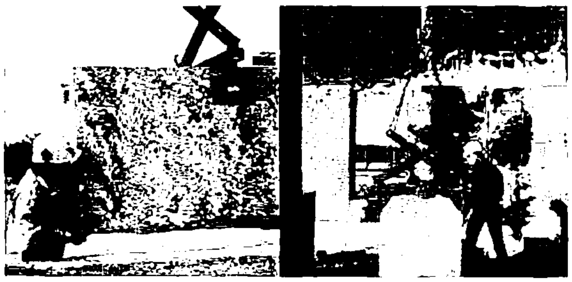

Figure 4. Perraudin stone assembly.

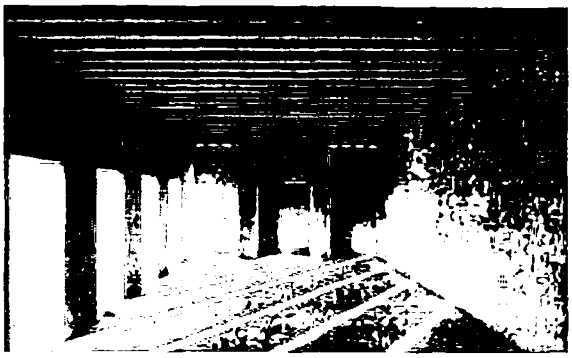

Figure 5. Winery, Gilles Perraudin.

In both of these projects and practices, the architects use digital fabrication in minor ways that effect meaningful changes. It is impossible to dissociate digital fabrication from the conditions that prepared and developed it, nor from all the effects it generates. CNC is not a benign solution to a technical problem but in this case carries deep social effects *and potentials*. In order to project effective theories, techniques and technologies in architecture, it is vital to substantiate the deep influences that shape technical practices. In architecture, we need to think and act more rationally about this presumably most rational of our endeavors. An expanded view of technology that includes its full assembly of social, economic, ecological, political, and technical forces would advance or conception and practice of technology in architecture.

[1] 'Tools always presuppose a machine, and the machine is always social before it is technical. There is always a social machine which selects or assigns the technical elements used.' Deleuze, Gilles and Claire Parnet. *Dialogues II*. Columbia University Press, New York. 1987. p. 70.

[2] Beck, Ulrich. *Risk Society: Towards a new Modernity*. SAGE Publications, London. 1992.

[3] Mumford, Lewis. Technics and Civilization. Harcourt Brace & Company: New York, 1963.

[4] Deleuze, Gilles. 'Treatise on Nomadology.' A Thousand Plateaus. University of Minnesota Press, Minneapolis. 1987.

[5] Childe, V. Gordon. "Rotary Motion." p. 187-215 of Singer, Charles, E.J. Holland, and A.R. Hall, eds. *A History of Technology. Vol. 1: From Early Times to Fall of Ancient Empires*. Oxford University Press: New York, 1955. In this volume, Harrison and Childe provide an excellent account of the partial rotary and full rotary motion tools for drilling and fire making in the archaic world.

[6] Harrison, H.S. "Fire-Making, Fuel and Lighting." p. 220-230 of Singer, Charles, E.J. Holland, and A.R. Hall, eds. *A History of Technology. Vol. 1: From Early Times to Fall of Ancient Empires*. Oxford University Press: New York, 1955.

[7] Reintjes, J. Francis. Numerical Control: Making a New Technology. Oxford University Press: New York, 1991.

[8] Mumford, Lewis. *Technics and Civilization*. Harcourt Brace & Company: New York, 1963. The topic of regularization that 'left no aspect of life untouched' is a pervasive theme of *Technics and Civilization*.

[9] Ibid. p 9-59. The Chapter on "Cultural Preparation" focuses on this series of developments in these adjacent practices.

[10] Ibid. Mumford concisely tracks the development of quantitative developments throughout *Technics and Civilization*.

[11] Smith, Merrit Roe. "Army Ordnance and the 'American system' of Manufacturing." in *Military Enterprise and technological Change: Perspective on the American Experience*. MIT Press: Cambridge, MA. 1985. p 39-86.

[12] Ibid. "Introduction." in *Military Enterprise and technological Change: Perspective on the American Experience*. MIT Press: Cambridge, MA. 1985. p 13-15.

[13] Noble, David F. America by Design: Science, Technology, and the Rise of Capitalism. Oxford University Press: Oxford. 1977.

[14] Melman, Seymour. The Permanent War Economy: American Capitalism in Decline. Simon and Schuster: New York. 1974.

[15] Osborn, Alex F. *The Optimism Book for Offices: How to Standardize and Systematize to Meet War-Created Business Problems*. Art metal Construction Co, Jamestown NY. 1918. This book provides an excellent period source for the mental habits of the relationship between war and industry at the end of World War I.

[16] Retijles, J. Francis. *Numerical Control: making a New Technology*. Oxford University Press, New York. p 134-140.

[17] Ibid. p. 141-163.

[18] Noble, *David F. Forces of Production: A Social History of industrial Automation*. Alfred A. Knopf: New York, 1984. p. 145-192. This chapter, "The Road not Taken," focuses on the alternatives to fully automated production methods. He shows that some these alternatives were adapted by Japanese and European counterparts and demonstrates how the alternatives provide a more supple system of production with fewer economical and social challenges.

[19] Kwinter, Sanford. 'The Cruelty of Numbers.' *ANY 10*. p. 60-62.

[20] Noble. p. 265-323. the chapter "Who's Running the Shop" focuses on the designed utopia and actual conditions of fully automated production and the increase of labor rather than decrease in labor, a theme throughout the book.

[21] Kieran, Stephan and James Timberlake. Refabricating Architecture. McGraw-Hill: New York, 2004. SHOP: Sharples Holden Pasquarelli, eds. *Versioning: Evolutionary Techniques in Architecture. Architectural Design*. Vol 72, no 5. Sept/Oct 2002. From the avant-garde to the rear guard, the literature of new production techniques ignores the social and technical histories of the very industries they aim to emulate.

[22] Some authors have contempt for the labor force in the building industry. See, for one example, Wachsmann, Konrad. *The Turning Point of Building: Structure and Design. Rheinhold Publishing Corp, New York. 1961. p 104, 116-7.*

[23] Kieran, p XII. From the very beginning of this book, the authors stir up the romantic image of the master builder.

[24] Noble, *David F. Forces of Production: A Social History of industrial Automation*. P.276-80.

[25] Kieran, p XI.

[26] Noble, David F. "Command and Performance: A Perspective on Military Enterprise and Technological Change." in *Military Enterprise and technological Change: Perspective on the American Experience*. MIT Press: Cambridge, MA. 1985. p. 329-346.