Sugar Machines and the Fragile Infrastructure of Commodities in the Nineteenth Century

by David Singerman*

ABSTRACT

This essay uses sugar machinery to explore the fragile infrastructure that allowed global commodity traffic to emerge. In the nineteenth century, the cane sugar industry transformed the Caribbean, the Hawaiian Islands, and much of the rest of the tropical world. Observers then and now tied sugar's revolutionary power to the invention and spread of advanced mechanical technologies. Yet the origins and lives of those machines themselves have remained obscure. The superficially effortless circulation of standardized material goods like sugar depended on carefully cultivated systems for managing people, paper, objects, and knowledge—and such things could not be standardized so easily.

INTRODUCTION

Sugar is both a central commodity in the history of capitalism and a model for students of that history.[1] As with any natural substance, understanding how capitalism transforms sugar into a commodity means understanding the technologies that make such commodification possible. Among commodities, however, sugar is distinctive in that sophisticated machinery has been its particularly close companion for hundreds of years.

The recognizable shape of the early modern Caribbean plantation emerged during the "sugar revolution" of the eighteenth century, when Europe turned whole islands

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[1] Sidney Mintz, *Sweetness and Power: The Place of Sugar in Modern History* (New York, 1985).

into sugar factories in order to slake its own addiction.[2] Planters designed their properties around the fact that the juice of the sugarcane, once cut, begins to ferment within a day. So plantations became what Sidney Mintz described as a "synthesis of field and factory" in which industry worked to agricultural rhythms and agriculture arranged itself to efficiently supply machines.[3] At the center of the plantation, no more than a day's carriage from the field, were the mill and the boiling-house, and inside them the plantation's large and costly technological objects: rollers, furnaces, cauldrons, troughs, and clay molds for drying the wet sugar.

From the beginning of the seventeenth century, sugar planters and allied natural philosophers tried hard to portray the process of sugar manufacture as mechanical rather than artful, driven by European ingenuity rather than enslaved people's know-how. In fact, as historians have long emphasized, and as contemporaries grumblingly acknowledged, making sugar was a complex art that required all the skill and craft of enslaved people, not merely their labor.[4] More recently, historians such as Eric Otremba and Daniel Rood have demonstrated that slaves were frequently responsible for improvements to machinery—improvements for which planters and savants inevitably claimed credit.[5]

In the nineteenth century, machinery was again key to a second sugar revolution that reconfigured the relationships between field and factory and between labor and capital. Whereas in 1800 all the sugar mills of the world were powered by water, wind, or animals, over the following decades European and North American firms began to produce mills driven by steam. With steam power came other machines, like centrifuges and sealed vacuum chambers, many of which were adaptations of devices already in use by beet-sugar producers in Europe. By 1860, steam drove 70 percent of the mills in Cuba, the best-capitalized and most technically advanced sugar producer.[6] Over the following decades, plantation estates consolidated into larger agricultural units built around huge factories, and new factories were constructed in undeveloped regions of the Caribbean and across the world. Sugar, purer and more consistent than ever before, glutted the world market. By the end of the century, slavery had been overthrown or abolished, replaced (at least de jure) by other systems of labor.[7]

This second revolution has, like the first, been analyzed in largely technological and deterministic terms. The intrinsic economies of scale of these new technologies,

[2] B. W. Higman, "The Sugar Revolution," *Econ. Hist. Rev.* 53 (2000): 213–36, on 213.

[3] Mintz, *Sweetness and Power* (cit. n. 1), 47.

[4] See, e.g., Richard S. Dunn, *Sugar and Slaves: The Rise of the Planter Class in the English West Indies, 1624–1713* (Chapel Hill, N.C., 1972); Manuel Moreno Fraginals, *The Sugarmill: The Socioeconomic Complex of Sugar in Cuba, 1760–1860*, trans. Cedric Belfrage (New York, 1976).

[5] Eric Otremba, "Inventing Ingenios: Experimental Philosophy and the Secret Sugar-Makers of the Seventeenth-Century Atlantic," *Hist. & Tech.* 28 (2012): 119–47; Daniel B. Rood, *The Reinvention of Atlantic Slavery: Technology, Labor, Race, and Capitalism in the Greater Caribbean*, 1st ed. (New York, 2017).

[6] Jonathan Curry-Machado, *Cuban Sugar Industry: Transnational Networks and Engineering Migrants in Mid-Nineteenth Century Cuba* (New York, 2011).

[7] The Cuban historian Manuel Moreno Fraginals argued that the island's planter elite abolished slavery in the late nineteenth century because slavery as a system, and slaves as a class, were incompatible with those planters' desires for mechanized and technically sophisticated production. Moreno Fraginals, *The Sugarmill* (cit. n. 4), 112; Moreno Fraginals, "Plantations in the Caribbean: Cuba, Puerto Rico, and the Dominican Republic in the Late Nineteenth Century," in *Between Slavery and Free Labor: The Spanish-Speaking Caribbean in the Nineteenth Century*, ed. Moreno Fraginals, Frank Moya Pons, and Stanley L. Engerman (Baltimore, 1985), 3–21.

combined with their higher cost, led to the "rationalization" of sugar production in the form of "central factories" that could take advantage of those efficiencies by processing much more cane from a much larger area.[8] From the seventeenth century to the twentieth, therefore, machines have been central to historians' understanding of sugar economies. Yet even as historians have made so much of the new technologies of sugar production, they have remained largely incurious about the machines themselves or who made them. This essay begins to tell the story of sugar machines in order to expose the fragile infrastructure upon which familiar Atlantic commodity networks were built.

The industrialization of sugar production affords an opportunity to incorporate the workshops of empire into the empire of sugar. Such workshops might be in England, or the United States, or France.[9] But mostly they were in Glasgow, Scotland. The city of Glasgow rose to mercantile prominence in the eighteenth century with the West India trade, and it became the heavy-engineering center of the nineteenth century after those merchants invested in mining, cotton, railroads, and shipbuilding.[10] And through 1914 Glasgow on its own produced 80 percent of the world's sugar manufacturing equipment.[11] Mirrlees Watson, perhaps the world's largest maker, dispatched over 2,000 mills from its 800-strong Glasgow workshop, "one of the most splendid and completely equipped engineering establishments" in Britain by the 1890s.[12] Yet for all its contemporary fame in the sugar economy—in 1878, the British consul in San Juan reported that "such well-known names as Tait and Mirelees [*sic*] and Buchanan are to be seen on scores of sugar plantations"—Glasgow has remained largely absent from historians' analyses of that economy.[13] When the city's manufacturers are mentioned, it is usually just to use the city's engineering reputation to add heft to claims about the technical sophistication of a new sugar factory.[14]

[8] Dale Tomich, "Commodity Frontiers, Spatial Economy, and Technological Innovation in the Caribbean Sugar Industry, 1783–1878," in *The Caribbean and the Atlantic World Economy: Circuits of Trade, Money and Knowledge, 1650–1914*, ed. Adrian Leonard and David Pretel, Cambridge Imperial and Post-Colonial Studies (New York, 2015), 184–216; J. H. Galloway, *The Sugar Cane Industry: An Historical Geography from Its Origins to 1914* (Cambridge, 1989), 139.

[9] Nadia Fernández-de-Pinedo and David Pretel, "Circuits of Knowledge: Foreign Technology and Transnational Expertise in Nineteenth-Century Cuba," in Leonard and Pretel, *The Caribbean* (cit. n. 8), 263–89, table 12.1, on 269.

[10] Michael S. Moss and John R. Hume, *Workshop of the British Empire: Engineering and Shipbuilding in the West of Scotland* (London, 1977), 3–5; T. M. Devine, "The Golden Age of Tobacco," in *Glasgow*, ed. Devine and Gordon Jackson (Manchester, 1995), 139–83; Richard Pares, "A London West India Merchant House 1740–69," in *The Historian's Business, and Other Essays*, ed. R. A. Humphreys and Elisabeth Humphreys (Oxford, 1961), 198–226, on 210.

[11] Fernández-de-Pinedo and Pretel ("Circuits of Knowledge" [cit. n. 9], 269) show that the large majority of sugar equipment came from Britain between 1844 and 1857, although during that period slightly more (264 vs. 233) grinding mills came from the United States.

[12] John Mayer, *Notices of Some of the Principal Manufacturers of the West of Scotland* (Glasgow, 1876), 66, 118.

[13] "Report by Consul Bidwell on the Trade and Commerce of the Island of Porto Rico for the Year 1878," in *Puerto Rico en La Mirada Extranjera: La Correspondencia de Los Cónsules Norteamericanos, Franceses E Ingleses, 1869–1900*, ed. Gervasio L. García Rodríguez and Emma Aurora Dávila Cox (Río Piedras, Puerto Rico, 2005), 165; Andrés Ramos Mattei, "Technical Innovations and Social Change in the Sugar Industry of Puerto Rico," in Moreno Fraginals, Moya Pons, and Engerman, *Between Slavery and Free Labor* (cit. n. 7), 158–78.

[14] The index for J. H. Galloway's *Sugar Cane Industry* does not even include an entry for "Glasgow," and while that for Noël Deerr's standard and encyclopedic *History of Sugar* does mention the names of specific machinery producers, it includes only an entry for Glasgow "as refining centre." Galloway, *Sugar Cane Industry* (cit. n. 8), 261; Noël Deerr, *The History of Sugar*, 2 vols. (London, 1949), 2:610.

For historians of science and capitalism, however, Glasgow's engineering workshops provide an opportunity to study just what forms of knowledge it takes to produce "standard" commodities on a global scale. It would be reductive to declare the relationship between sugar, on the one hand, and the machinery for making it, on the other, to be a case for the history of technology rather than the history of science. Historians of science have long accepted that factories and plantations, as well as a wide variety of spaces of exchange, are zones where knowledge can be produced just as much as in a laboratory.[15] Those who build the infrastructure for knowledge production in the marketplace merit no less scrutiny than do makers of scientific instruments. This is especially true in the sugar market for two reasons. First, as this essay shows, building industrial machines for sugar depended on networks and skills of information management that were just as complex as any instrument builder's. Second, the commodity status of nineteenth-century sugar depended more heavily on modern science than any comparable natural object. Yet the more sugar seemed to become immutable and mobile, the more that machines for making it became customized and unruly. The circulation of standardized natural goods—superficially effortless—in fact depended entirely on deeper currents of people, objects, and knowledge that could not be standardized so easily.

Over the course of the nineteenth century, sugar acquired its modern reputation as a nearly ideal commodity. The Cuban sociologist Fernando Ortiz could write in 1940, for instance, of the "equal chemical and economic standing of all the sugars of the world, which, if they are pure, sweeten, nourish, and are worth the same."[16] Mechanically processed, sugar seemed to effortlessly transgress social and even natural boundaries: it "is born brown and whitens itself; at first it is a syrupy mulatto and in this state pleases the common taste; then it is bleached and refined until it can pass for white [and] travel all over the world."[17] But just like the act of passing, there was nothing easy about the global travel of pure sugar, nor anything natural about the categories that shaped it. Instead, sugar's commodification required constant labor on the part of factory workers, chemists, and engineers, just as its production had required the skills of slaves not long before.[18] Even so, the labor that produced sugar from plants was subjected to the de-skilling and standardizing pressures of capital, pressures akin to those facing workers in late eighteenth-century shipyards or twentieth-century manufacturing.[19]

James Secord and Kapil Raj, among others, have called for histories of science in transit, lest an emphasis on the specific local cultures of scientific knowledge can distract from the ultimate objective of understanding how knowledge moves beyond that culture.[20] Efforts to standardize practices, especially in the nineteenth century, fre-

[15] Harold J. Cook, *Matters of Exchange: Commerce, Medicine, and Science in the Dutch Golden Age* (New Haven, Conn., 2007).

[16] Fernando Ortiz, *Cuban Counterpoint: Tobacco and Sugar*, trans. Harriet De Onís (Durham, N.C., 1995), 24–5.

[17] Ibid., 9.

[18] David Roth Singerman, "The Limits of Chemical Control in the Caribbean Sugar Factory," *Radic. Hist. Rev.* 2017, no. 127 (2017): 39–61.

[19] William J. Ashworth, "'System of Terror': Samuel Bentham, Accountability and Dockyard Reform during the Napoleonic Wars," *Soc. Hist.* 23 (1998): 63–79; David F. Noble, *Forces of Production: A Social History of Industrial Automation*, 1st ed. (New York, 1984), chap. 1.

[20] James A. Secord, "Knowledge in Transit," *Isis* 95 (2004): 654–72; Kapil Raj, *Relocating Modern Science: Circulation and the Construction of Knowledge in South Asia and Europe, 1650–1900* (New York, 2007).

quently involved the circulation of standard objects. Precision devices only travel fitfully and after much social work has smoothed their way, but that travel is what makes it possible to claim that knowledge is universal.[21] And likewise, historians have supposed that the distribution of standard objects and devices has made the easy travel of commodities and other artifacts possible. Those standards sometimes take exemplary form, such as jars of sugar or samples of cotton, and sometimes the form of inspection procedures and instruments.[22] The "highly sophisticated machinery" that filled central factories in the late nineteenth century made possible the efforts of factory owners to standardize their workers' labor.[23]

Like Courtney Fullilove's plant genes, however, these sugar machines were fundamental to a standardized commodity precisely because they resisted standardization themselves.[24] Moreover, factory owners' efforts to de-skill labor depended on that idiosyncrasy, on machines tailored by Glaswegian manufacturers to their sugar factory's exact requirements. Well into the twentieth century, as this essay shows, sugar machinery was designed and maintained through individualized systems of design, irregular channels of communication, and the ability to recontextualize people and things. Glasgow's sugar machinery should join uranium and financial derivatives in reminding us that human craft, skill, and labor are impossible to eliminate in the infrastructures of commodity production. They can only be shuffled out of sight.[25]

PEOPLE

Sometime around 1800, one of Glasgow's West India sugar merchants placed an order for a sugar mill with a flax millwright named James Cook. By 1805, Cook had so many orders that he was forced to move his workshop to a larger site on the south bank of the Clyde, and within two decades Cook's works were among the city's leading industrial operations.[26] So many engineers were trained there, wrote one industry observer a century later, that Cook's works became known as "The College." His firm anchored a cluster of sugar-engineering works on the south side of the city.[27]

These firms, like the others that would dominate Glasgow's sugar-machinery business, all began as joint partnerships. Some partners contributed capital, others engineering expertise, and others familiarity with or connections to the West India merchant class.[28] In the mid-1860s, for instance, the young engineer Duncan Stewart was

[21] Marie-Noëlle Bourguet, Christian Licoppe, and Heinz Otto Sibum, "Introduction," in *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century* (London, 2002), 1–19, esp. 3–9; see also M. Norton Wise, ed., *The Values of Precision* (Princeton, N.J., 1995); Joseph O'Connell, "Metrology: The Creation of Universality by the Circulation of Particulars," *Soc. Stud. Sci.* 23 (1993): 129–73.

[22] Michel Callon, Cécile Méadel, and Vololona Rabeharisoa, "The Economy of Qualities," *Econ. & Soc.* 31 (2002): 194–217, esp. 198–9; Ken Alder, "Making Things the Same: Representation, Tolerance, and the End of the Ancien Regime in France," *Soc. Stud. Sci.* 28 (1998): 499–545.

[23] Moreno Fraginals, "Plantations" (cit. n. 7), 8.

[24] Courtney Fullilove, "Microbiology and the Imperatives of Capital in International Agro-Biodiversity Preservation Projects," in this volume.

[25] Gabrielle Hecht, *Being Nuclear: Africans and the Global Uranium Trade* (Cambridge, Mass., 2012); Vincent Antonin Lépinay, *Codes of Finance: Engineering Derivatives in a Global Bank* (Princeton, N.J., 2011).

[26] Robert Harvey, *Early Days of Engineering in Glasgow* (Glasgow, 1919), 8.

[27] Michael Pacione, *Glasgow: The Socio-spatial Development of the City*, World Cities Series (Chichester, 1995), 75–7; Harvey, *Early Days* (cit. n. 26), 9.

[28] S. G. Checkland and Anthony Slaven, eds., *Dictionary of Scottish Business Biography, 1860–1960* (Aberdeen, 1986), 188–9.

offered the position of chief engineer by a Glasgow merchant firm that owned seven Demerara estates.[29] Although he had recently started his own London Road Ironworks, Stewart accepted the appointment in order to "master the process of making sugar from the cane," which he could not do just by observing Scottish refineries. When he returned to Glasgow, a biographer wrote later, he brought "wider technical knowledge which proved to him of greater worth than the mere possession of capital."[30]

The "technical knowledge" that Stewart brought back from his years overseas incorporated the whole complex of sugar production, human as well as mechanical. His reputation was built on a series of patents for hydraulic rams that regulated the pressure a mill's rollers applied to the cane.[31] Early modern sugar mills were notorious for maiming or killing human beings, but in a steam mill it was far less likely that a body part of a worker would get caught. Instead, Stewart set to work on his hydraulic cylinders to prevent damage from an overload of cane. Just as Lee Vinsel shows elsewhere in this volume how the auto industry disclaimed responsibility for protecting against "accident-prone" drivers,[32] so too the management of sugar factories invariably blamed a broken roller on the "injudicious and unskilful [*sic*]" workers. An "accident," in sugar engineering parlance, switched from meaning an injury to a human to an injury to a machine. This explains why Stewart's patented hydraulics were called a "safety device": not because they prevented a person from being milled but because they ensured the safety of the capital investment in machinery.[33]

The engineers who traveled back and forth between the Caribbean and Britain played crucial roles as go-betweens, mediating the relationship between sugar estates and the firms that manufactured their machines.[34] Cheaper and faster oceanic travel meant these engineers could easily spend the grinding season supervising a factory in the Caribbean, and the rest of the year elsewhere, sometimes in the cane fields of Louisiana, which harvested their cane on a different schedule, or in beet-sugar factories. Boosters of Glasgow industry argued that these engineers' voyages provided unusually direct experience with the processes of sugar making: "By their long connection with the trade, and especially from the circumstance that principals of several of the firms engaged in it have travelled in the sugar-growing countries of both hemispheres, they have come face to face with the planters upon their estates, and acquired an exact acquaintance with their wants." Through such careful management of foreign customers, the sugar-machinery business "like the sugar plantations themselves . . . has

[29] T. M. Devine, "An Eighteenth-Century Business Élite: Glasgow-West India Merchants, C. 1750–1815," *Scot. Hist. Rev.* 57 (1978): 40–67.

[30] "The Implement and Machinery Review," 1 September 1886, in "Newspaper cuttings," TD185/5, Records of Messrs. Duncan Stewart & Co., Mitchell Library, Glasgow.

[31] "The story of Duncan Stewarts [sic], and their association with the British beet sugar industry," address given by Mr. K. S. Arnold at the General Managers' Annual Conference of the British Sugar Corporation at Peterborough, 1 June 1955, University of Glasgow Archives & Special Collections, Records of Duncan Stewart & Co., Ltd., GB 248 UGD 052/1/4/3, University of Glasgow Archives & Special Collections (repository no. GB 248), Glasgow (hereafter cited as "UGA").

[32] Lee Vinsel, "'Safe Driving Depends on the Man at the Wheel': Psychologists and the Subject of Auto Safety, 1920–55," in this volume.

[33] A. J. Wallis-Tayler, *Sugar Machinery: A Descriptive Treatise Devoted to the Machinery and Processes Used in the Manufacture of Cane and Beet Sugars* (London, 1895), 36.

[34] For the entrepreneurial dispersal of British engineers overseas, though neglecting the kinds of networks that produced the movement of engineers in sugar, see R. A. Buchanan, "The Diaspora of British Engineering," *Tech. & Cult.* 27 (1986): 501–24.

been anxiously, intelligently, and enterprisingly cultivated."[35] One engineer, for instance, "began his life of wandering" immediately upon joining Duncan Stewart's company as an apprentice in 1876, a journey that took him to the company's clients in Argentina, Barbados, and Cuba, as well as to its displays at international exhibitions.[36] Most of the machinery makers in Glasgow's other engineering industries did not need to travel such distances to see their products in action.

Planters came to rely on traveling engineers as crucial intermediaries with the firms from whom they wished to order new equipment or replacement parts. Purchasing agents who spent most of their time in Britain were better placed to communicate with engineering firms, but too far from the plantation to know what needed ordering. By contrast, itinerant engineers were uniquely positioned to understand how sugar factories actually worked.[37] While many such travelers were clearly employed by a particular British firm, plenty of others exploited oceanic distance. They might, for instance, maintain a consulting position for a Glasgow firm while still working for one or more sugar estates. Not infrequently an engineer would earn a commission from the plantation for ordering a machine from a firm and then be hired by the same firm to install that very machine.

W. H. Ross, an engineer who placed orders for many Cuban estates and was a confidant to their American owners, traveled back and forth between customers in Havana and manufacturers in New York, Glasgow, and Liverpool.[38] For instance, Edwin Atkins, the Bostonian owner of several Cuban factories, asked Ross's "opinion of the approximate value of a new mill del[ivere]d at Cienfuegos . . . made by Tate Mirless & Watson [*sic*]" and left much up to Ross himself to decide.[39] Shortly after he had purchased a plantation called Soledad, Atkins wrote Ross "giving order for a mill for regrinding on Soledad, you will note that we leave the matter in its detail pretty much to your judgement [*sic*], as I am sure you will take [care to] give us only the best; and your long experience in these matters make[s] your judgment of value." What made Ross valuable was not only his experience with sugar in general but with Atkins's new plantation in particular: "You know the kind of grinding we aim at doing, and trust you will govern your work in accordance."[40] To maintain himself in Mirrlees Watson's good graces, Ross asked Atkins for data about the performance of the sugar boiling equipment, which Atkins allowed Ross to share with the manufacturer.[41] Those who set up shop in Britain, trying to manage Caribbean affairs remotely, did not have access either to orders or to the currency of Atlantic information; as a result, they frequently found themselves without clients.[42]

In 1883, the Manchester merchants N. P. Nathan's & Sons purchased a full sugar-production arrangement from Duncan Stewart for a site in the Canary Islands. That

[35] Mayer, *Principal Manufacturers* (cit. n. 12), 116.
[36] *Beardmore News*, November 1923, Records of Duncan Stewart & Co., Ltd., UGD 052/1/4/2, UGA.
[37] Curry-Machado, *Cuban Sugar Industry* (cit. n. 6), chap. 3.
[38] Mirrlees Watson Order Book, 1891, Job no. 386, Records of Mirrlees Watson Co., Ltd., sugar machinery manufacturers, Glasgow, Scotland, UGD 118/2/4/10, UGA. On W. H. Ross, see Fernández-de-Pinedo and Pretel, "Circuits of Knowledge" (cit. n. 9), 273.
[39] Edwin Atkins to W. H. Ross Esq., 22 August 1885, II.6.287, Atkins Family Papers, Massachusetts Historical Society, Boston (hereafter cited as "MHS").
[40] Atkins to Ross, 17 April 1888, II.7.394, Atkins Family Papers, MHS.
[41] Atkins to Ross, n.d., II.8.260, and 14 August 1889, II.8.287–88, Atkins Family Papers, MHS.
[42] Curry-Machado, *Cuban Sugar Industry* (cit. n. 6), 87–90.

price included everything needed for a factory: a horizontal engine with double gearing, a sugar mill with hydraulics, a fifty-foot cane carrier, clarifiers, filter presses, a triple-effect evaporator, vacuum pan, four centrifugals, and molasses tanks, plus piping, mounting, staging, spares, and tools for erecting, all of which cost £7,304.[43] After the parts had been produced in the works, the entire machine was assembled next door in the erecting shop, tested as much as possible without any sugar, and photographed. Then it was disassembled, packed, and shipped, along with erecting tracings and photographs (fig. 1).[44] For the manufacturer, those photographs served as insurance against future claims and, along with the tracings, were used to reconstruct the machines after delivery. Unlike the iconic TEA (transversely excited atmospheric) lasers and air pumps of science studies, these reconstructions of sugar machines were attempts to put together a fixed set of existing parts, not build copies from scratch based on two-dimensional representations or textual descriptions.[45] But clearly the engineers at Duncan Stewart believed paper insufficient, and the tacit skills of knowledgeable people necessary. One of the firm's engineers, Robert Gilbert, accompanied the Nathan's order to the Canaries to supervise.

Although he was Duncan Stewart's eyes and hands, Gilbert was legally an independent contractor. In November 1883, he signed a contract directly with Nathan's, witnessed by the manager of Duncan Stewart and the company clerk. The main task for which he had been hired, at £5 a week plus "suitable Board and Lodging," was to supervise "the erection of and fitting and putting into working order, of Cane Crushing and Evaporating Machinery."[46] Once in Las Palmas, Gilbert was responsible for the machinery, including its unloading from the ship.

Individuals such as Gilbert, capable of supervising the construction of a whole sugar factory, were in short supply. The terms of his contract as a traveling erecting engineer emphasize the difficulty of the task. He was to obey orders from Nathan's, their manager in the Canaries, or their attorneys. At the same time, Gilbert was also obliged to "devote his whole time and attention to and employ his whole art and skill in the said erection and fitting up of the said machinery, and in getting the same in to proper and satisfactory working order."[47] Gilbert could not rely on quick or frequent communication with those who had designed the machines, and at the same time, his erstwhile employers were stifled in their efforts to understand what was going on.

Contracted erecting engineers sent as agents of a firm did not necessarily keep their principals apprised of their activities. In July 1884 Gilbert was still in the Canaries, and the personnel of Duncan Stewart were not even sure of how the work was progressing. He had not kept in close touch. The manager of the works in Glasgow asked Gilbert to "kindly write to us on receipt of this and let us know when you expect to come home." Not only did they want to know how his mission was going, but they needed him back in Glasgow so they could ship him off again—this time on a mission

[43] Duncan Stewart Cost Book 1881–1901, p. 18, UGD 052/1/1/1, UGA.

[44] It is not clear when firms began using progress photographs; vol. 1 of A. & W. Smith's photograph albums is dated 1907. UGD 118/1/5/1, UGA.

[45] Harry Collins, "The TEA Set: Tacit Knowledge and Scientific Networks," *Sci. Stud.* 4 (1974): 165–85; Steven Shapin and Simon Schaffer, *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life* (Princeton, N.J., 1985), 229.

[46] "Copy minute of agreement between N. P. Nathan's Sons and Robert Gilbert (Nov. 1883)—Forbes and Bryson, writers, Glasgow," UGD 052/1/7/2, UGA.

[47] Ibid.

Figure 1. *A. & W. Smith centrifugals, 1915, with note affixed: "this photograph should be given to the engineer who is to erect the machines." Records of Mirrlees Watson Co., Ltd. (cit. n. 38), UGD 118/1/51, UGA.*

to Brazil, accompanying "a large Sugar Plant which will be ready for shipment early next month."[48] He missed that trip. He was still in the Canaries in mid-September, and the sugar factory was still not finished, awaiting replacement parts from Duncan Stewart. "We have sent as much of the details as you have ordered," the company wrote, "as we possibly could in the short time they gave us before the ship sailed." The tyranny of distance worked both ways, frustrating both Gilbert's attempts to get his parts and Duncan Stewart's attempts to recall him.[49]

A year and a half after he had left Glasgow, in May 1885, Gilbert was still in the Canaries and still waiting for parts. They had been shipped, at least, just in time to be installed for the next grinding season. "We hope therefore all will reach you in good time so that you may be able to start the factory to [crush] the greater part of the crop satisfactorily," the firm wrote. Despite the delays and frustration, however, the presence of an engineer like Gilbert could serve a firm's interests. While twiddling his

[48] David. H. Andrew to Robert Gilbert, 7 July 1884, UGD 052/1/7/4, UGA.

[49] Duncan Stewart & Co. to Robert Gilbert, 15 September 1884, to Arucas, Canary Islands, UGD 052/1/7/5, UGA. On the "tyranny of distance," see Jim Endersby, "A Garden Enclosed: Botanical Barter in Sydney, 1818–39," *Brit. J. Hist. Sci.* 33 (2000): 313–34.

thumbs in the Canaries, Gilbert had been in contact with other planters and was on the verge of securing orders for two additional factories.[50]

Such orders were capital expenses that plantations hoped to undertake only once or twice a century. A glance at company order books shows that plantation owners usually ordered just one mill-and-engine combination at a given time, and rarely more than two. Properly maintained, such a pair might still match the efficiency of new machines fifty years later.[51] One of Mirrlees Watson's first mills, shipped in 1850, was not broken up until 1927.[52] Even more impressively, while in St. Lucia in 1973, Prince Charles stumbled across a rusting Mirrlees mill that was over a century old.[53] The bulk of the work of the engineering firms was not on new machines but on extensions, additions, and repairs to old ones. As the next section shows, the phenomenal cost and mass of these machines shaped both the plans of the sugar producer and the information demanded by the engineering firm.

PAPER

While mills lasted for decades in the Caribbean, their paper representations were carefully guarded back in Glasgow, where engineering companies were reluctant to part with original paper plans long after they had been turned into metal.[54] The transatlantic history of the equipment that filled the industrial sugar factory is thus not only a story of attenuated communication but also a story of difficult maintenance at a distance.[55] Historians and other scholars are increasingly interested in studying maintenance and disrepair as ordinary states of affairs, rather than ones that are extraordinary or "pathological."[56] Sugar machinery spent little time at factory spec, as the hot, noisy, and humid factory placed immense demands on people and metal. During the six-month grinding season, a mill was run almost around the clock. Every day brought more things to lubricate and to tighten; every week or two everything had to be thoroughly inspected. At the end of each season the machines were partly dismantled and packed away to protect them from the humidity, a curious combination of robustness and impermanence.[57] In such an environment, machines broke often, and when they broke they were far from the tools and expertise that had made them. Historians of the sugar industry have largely paid attention to when devices were invented or, more usefully, when they were widely adopted. But for most of their lives sugar machines were "old, existing things" rather than new ones, and they ought to be analyzed as such.[58]

[50] Duncan Stewart & Co. to Robert Gilbert, 21 May 1885, to Arucas, Canary Islands, UGD 052/1/7/6, UGA.

[51] Sugar Department Letterbooks, Mirrlees Watson & Co., Records of Mirrlees Watson Co., Ltd., UGD 062 1/3/1, UGA.

[52] Mirrlees Watson Mill and Krajewskis Order Book, UGD 118/2/4/37, UGA.

[53] "Mirrlees, Tait & Watson, Eglinton Works, Cook St., Engineers," AGN 479, Mitchell Library, Glasgow.

[54] Moss and Hume, *Workshop* (cit. n. 10), 162.

[55] David Edgerton, *The Shock of the Old: Technology and Global History since 1900* (New York, 2006), 77. On the perils of managing seventeenth-century sugar plantations at a distance, see Dunn, *Sugar and Slaves* (cit. n. 4), 200–201.

[56] Simon Schaffer, "Easily Cracked: Scientific Instruments in States of Disrepair," *Isis* 102 (2011): 706–17, on 707.

[57] Curry-Machado, *Cuban Sugar Industry* (cit. n. 6), 80–2, 94–5.

[58] Andrew Russell and Lee Vinsel, "Innovation Is Overvalued: Maintenance Often Matters More," *Aeon*, https://aeon.co/essays/innovation-is-overvalued-maintenance-often-matters-more (accessed 16 September 2017).

In order to be able to fulfill requests for replacement parts, engineering firms made it their business to know the fate of their machines many decades after original manufacture. The annotations in the margins of the Mirrlees Watson mill order book testify not only to the kind of information the firm wanted but also to the process by which that information was obtained (fig. 2). For example, mill number 360 was originally purchased for the Caledonia estate in Cuba in March 1859. A marginal note shows that in 1886 the mill was transferred to San Isidro, and whoever recorded that move took care to note the letter that carried it: number 9367 in 1904, fifty-five years after the machine was first bought. Or mill number 449, a horizontal mill sent to the Armonia estate in Cuba in June 1861. In 1903, the company received word that the mill unit had been transferred to La Reglita on the island. But the next year, they received conflicting information: perhaps it was only the accompanying engine, number 365, that had been moved. Other entries note the company's own modifications, like the one for mill 723: built in 1869 for Demerara as a three- or four-roller mill, it was expanded in 1889 to five rollers, "reverted" to three some years later, and finally sold to Bradford estate.[59]

These were fragile systems for acquiring knowledge. In December 1857, the Cuban owner of the Soledad plantation purchased a mill with thirty-inch-wide rollers from Mirrlees Watson, number 257. A few years later, the San Antonio estate purchased mill number 445, which sometime in the next two decades was sold to Soledad. In 1882, Edwin Atkins came into possession of Soledad by foreclosure and found its Mirrlees apparatus to be older than he wanted. "We replaced it with more modern machinery," he recalled, but "it was still in good condition and we sold it to another estate."[60] His new mill had significantly larger rollers—thirty-eight inches in diameter, the largest that Mirrlees then fabricated. The property of the estate when Atkins took it over also included mill 1406, which Mirrlees had just shipped there in February 1883. After activity in this secondary market, it might take Mirrlees Watson years to find out, despite yearly contact between Atkins and Mirrlees's agent, if they found out at all. The last time Mirrlees's books record mills 257 and 445, for example, they are at Soledad. If Atkins sold them, the engineering firm never knew.[61]

Rarely could sugar factories upgrade their entire production lines at once, so they cobbled together pieces of others. Sugar factories were agglomerations of machines from different makes as well as different vintages, so Glaswegian firms needed to know how their apparatus were being fitted together, not just who owned what. In 1907, the purchasing agent Victor Mendoza ordered mill number 1745 for Cuba's Central Mercedita. This was a standard three-roller unit, which the company recorded was "making with mills 1405, 1712 & 1713 a 12 roller train." The position of the unit in the "train" was important to know because it helped predict pressure and wear patterns and thus the likelihood of the unit's breakage. Similarly, Dos Hermanos in Cuba took delivery of mill 1326 in 1882 and mill 1555 ten years later. Each mill came with an engine and gearing, but in 1909 the company received word, via Mendoza, that the engines and mills had been switched, so that the later engine was driving the earlier

[59] Mirrlees Watson Mill and Krajewskis Books no. 1 (1841–1912) and no. 2 (1883–1964), UGD 118/2/4/37 and 118/2/4/38, UGA.

[60] Edwin Farnsworth Atkins, *Sixty Years in Cuba: Reminiscences of Edwin F. Atkins* (Cambridge, Mass., 1926), 93.

[61] Mirrlees Watson Mill & Krajewskis Book no. 1 (cit. n. 59).

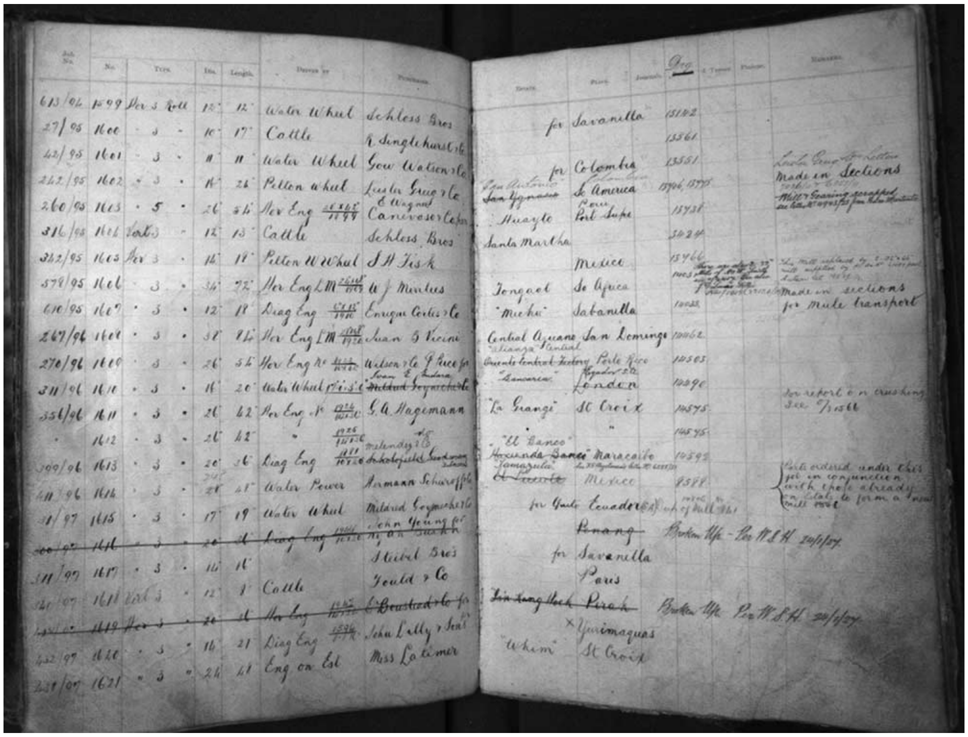

Figure 2. *Mirrlees Watson mill order book, showing annotations where new information was received. Records of Mirrlees Watson Co., Ltd. (cit. n. 38), UGD 118/2/4/37, UGA.*

mill. The earlier mill's rollers were both longer and wider than the newer ones and thus would experience different pressures and volumes of cane, feature different patterns of wear, demand different amounts of power, and have different life spans.[62]

Engineering firms maintained their relationships with overseas clients by exchanging drawings and tracings. Conversely, Caribbean engineers used Glasgow firms' practices of record-keeping to test their reliability as manufacturers and credibility as suppliers of parts (fig. 3). In 1838, the locomotive engineer Peter McOnie, having fallen on hard times, wrote to a friend in the West Indies seeking work on an estate but was advised to set up a repair shop in Scotland instead.[63] When this friend needed spares for his Cook-made mill, he needed to have "sent home such complete sketches with all sizes carefully marked" before McOnie could produce working patterns for the forge.[64] Later, when the plantation needed a new mill, the friend "made careful drawings of the set he required and sent them home to McOnie, who started at once to make working drawings from the sketches." The estate's owners were skeptical of McOnie's ability to complete the order and only signed the deal "on Mr. McOnie explaining that he had working drawings already made to sketches from D. Cook's engine and sugar mill in Trinidad."[65]

[62] Mirrlees Watson Mill & Krajewskis Book no. 2 (cit. n. 59).
[63] Moss and Hume, *Workshop* (cit. n. 10), 31.
[64] Robert Harvey, "The History of the Sugar Machinery Industry in Glasgow," *Int. Sugar J.* 19 (1917): 57–61, 112–7, on 112.
[65] Ibid., 113.

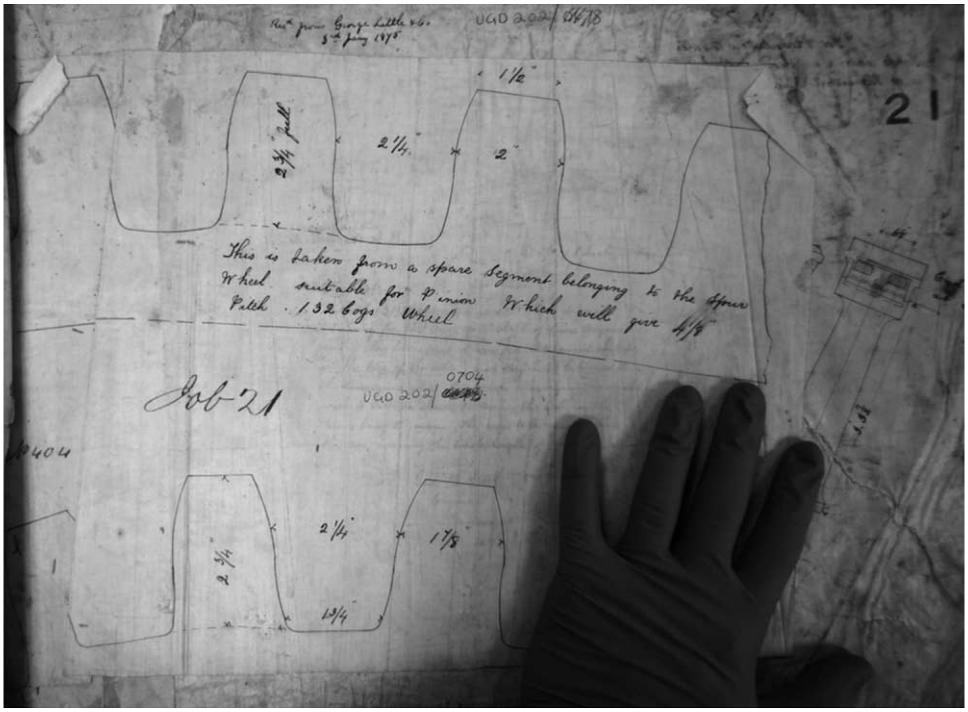

Figure 3. *Full-size tracing of gear teeth of a sugar mill spur wheel sent to Mirrlees Watson, with hand for scale. Records of Mirrlees Watson Co., Ltd. (cit. n. 38), UGD 202/0704, UGA.*

This was true not only for new partnerships but for long-standing ones as well. An engineer in Puerto Rico, at the end of the 1864 sugar season, sent Mirrlees Tait—Watson joined in 1868[66]—a request for two new mill cheeks on behalf of the estate of Señors Patxot and Polidura in Mayaguez, "as they have split the two this last crop across by the centre brass." The correspondent even told them where to look in their own books. "Knowing that *you have always your plans and models of the machines at hand in case any accident such as above should happen*, for that reason I only send you the number of mill 374, and year 1859, *thinking that is quite enough*." He attached only a "small sketch" to show where the original pieces had failed. But he also wanted the firm's guarantee that the new cheek would be functionally identical, "finished so that the same brasses will suit when necessary."[67] A few weeks later the firm received another letter on the same matter from a different correspondent, identifying the estate as "Ysabel for which you have executed before this several orders."[68] According to the company's books, Ysabel's mill was still being driven by a water wheel, and this client had required an unusually large number of drawings.[69] The engineer Thomas Dodd, writing in 1859 for Estate Florida near Ponce, on the southern

[66] Moss and Hume, *Workshop* (cit. n. 10), 33.
[67] Drawing from C. A. Hasche in Mayaguez, dated 8 July 1864, UGD 202/2430, UGA; emphasis added.
[68] Ibid.
[69] Mirrlees Watson Mill & Krajewskis Book no. 2 (cit. n. 59). See also Descriptive Drawings Index, "Horizontal Sugar Mills," p. 502, UGD 118/2/7/12, UGA.

coast of Puerto Rico, enclosed a drawing of the links of a driving chain of which he needed twenty-four feet. "I forgot to take the diameter of the pitch wheels to give the curve of the links," he wrote, "*but you will have it in your dimension Books*."[70] Dodd, apparently satisfied, was still ordering from Mirrlees in 1891.[71]

As a result of their importance, draftsmen could be powerful figures in a sugar engineering firm, and drawing sugar machines required knowledge that counted as specialized even within the world of engineers. The ascent of Robert Harvey, who began as the best turner at James Cook's lathes, emphasizes these points. In the early 1830s, Harvey's skill as a portraitist led to a successful trial as a draftsman. After a year, Harvey left in search of a raise and was hired by Neilson, a general engineering works that had received an order from Cuba for an engine and mill. Neilson's manager, William Tait, told the partners that he could not build a sugar mill "as it was all strange to him," so he sought out Harvey for advice. The expertise acquired from working with Harvey later brought Tait into business with James Mirrlees, forming the largest and longest-lasting of the Glasgow sugar partnerships, while Harvey returned to his old firm as managing partner in the 1850s.[72]

In the 1830s, when Harvey moved into the drafting office, self-trained draftsmen took techniques from many exemplars and sources, from drawing manuals to magazines. A decade or so later, however, Harvey began to teach mechanical drawing to supplement his income: first at home in the evenings, then in the Mechanics' Institute, and at the Government School of Design, which became the Glasgow School of Art.[73] The demand for these courses testified to the attraction of the potentially more "gentlemanly" nature of the work performed by draftsmen compared to even skilled factory work—as, indeed, did Harvey's willingness to take an initial pay cut.[74] At the same time, however, educational sites like the Mechanics' Institute, and Anderson's Institution, from which it had split, helped render draftsmen the "invisible technicians" of engineering workshops, including those in sugar.[75]

By the latter decades of the century, sugar engineering firms, like those in other lines of manufacture, boasted large drawing offices that included men of widely varying skills, training, background, and status.[76] In organization and discipline, the drafting office of a firm came to resemble the works itself.[77] Some draftsmen were themselves designers of machinery, while others worked to translate those designs into shapes that the works could manufacture. The largest group of draftsmen worked as tracers, skilled

[70] Chain link drawing from Thomas Dodd, 16 September 1859, Records of Mirrlees Watson Co., Ltd. (cit. n. 38), UGD 202/1555, UGA; emphasis added.

[71] Mirrlees Watson Order Book, 1891 (cit. n. 38), Job. no. 304.

[72] Harvey, "History" (cit. n. 64), 59.

[73] Harvey, *Early Days* (cit. n. 26), 11.

[74] Peter Jeffrey Booker, *A History of Engineering Drawing* (London, 1963), 134.

[75] See Steven Shapin, "The Invisible Technician," *Amer. Scient.* 77 (1989): 554–63; Larry Stewart, "Assistants to Enlightenment: William Lewis, Alexander Chisholm and Invisible Technicians in the Industrial Revolution," *Notes Rec. Roy. Soc. Lond.* 62 (2008): 17–29; George Emmerson, *Engineering Education: A Social History* (Newton Abbot, England, 1973), 91–100, 184–5. See also Steven Shapin and Barry Barnes, "Science, Nature, and Control: Interpreting Mechanics' Institutes," *Soc. Stud. Sci.* 7 (1977): 31–74; Maxine Berg, *The Machinery Question and the Making of Political Economy, 1815–1848* (New York, 1980), 147–55.

[76] See John Laidlaw letters, T-HB 72, Mitchell Library, Glasgow. For apprentices at Duncan Stewart and their salaries, see TD 158/11, Apprenticeship Book, Mitchell Library.

[77] Frances Robertson, "Manufacturing the Visual Economy in Nineteenth-Century Britain" (paper presented at the annual meeting of the International Society for Cultural History, Lunéville, France, 2 July 2012).

at making many reproductions of the same image. The more complex process of manufacturing itself now demanded multiple copies of drawings where just one had previously been necessary, and what counted as an adequate copy depended on the person for whom it was being produced, their place in the workshop, and what information they needed from a drawing.[78] Finally, some drawings needed to impress customers; as Frances Robertson points out, "Superhumanly neat inscriptions on paper functioned as a promise to deliver the goods in the material world."[79]

Outside the drafting office, the patternmakers were responsible for translating draftsmen's designs into wooden forms. Like its drawings, a firm's patterns were its most crucial assets, and the ability of a company to classify, store, retrieve, and reuse drawings and patterns was key to its fortunes.[80] So patterns, like the machines they represented, were built to last. In constructing a pattern by gluing multiple cross-grained layers of wood, the patternmaker had to consider how useful the pattern might be in the future and build it accordingly: cheaply if it was to be discarded, or solidly to last, with layers of shellac to protect it from warpage and precisely designed joints that would not alter with age.[81] When the partnership that James Cook founded finally dissolved, the managing partner sold the works but "bought all the patterns and drawings."[82]

The Puerto Rico engineers Robert Bennett and Thomas Dodd sent many orders to the Mirrlees firm in the late 1850s and early 1860s. "As I am not exactly acquainted with your patterns" for juice clarifiers, wrote Bennett in 1857, "I have sent you a sketch of the position they are to be placed with regard to the engine and you can make any other alterations that may be required to fit your patterns."[83] They wrote again on the eve of the 1861 grinding season to order a new engine, cane carrier, and shafts for Estate Vista-Alegre. "Cane carrier sides to be fitted to your mill No. 116," but "if the patterns have been altered since [the mill was made] let us know & we will send you a sketch, as we have not had time to do so."[84] The next year they ordered new cheeks for the mill but trusted the company's records less, sending them the "shape of cheek . . . taken of casting." They added that "the drawing you have corresponds with these dimensions so you can make the gudgeons [to] your drawing."[85] Neither drawings nor patterns, however, dictated the construction of sugar machines. The cooperative processes of design and construction meant that shop-floor workers had to use their judgment to figure out how to translate paper to wood and then to iron and steel.[86]

[78] Moss and Hume, *Workshop* (cit. n. 10), 160; Booker, *History* (cit. n. 74), 133.

[79] Frances Robertson, "Delineating a Rational Profession: Engineers and Draughtsmen as 'Visual Technicians' in Early Nineteenth Century Britain" (paper presented at the Three Societies Meeting, Philadelphia, 11 July 2012).

[80] "Inventory and Valuation of Machinery Plant, and Tools at Eglinton Engine Works, Cook Street, Glasgow, made by Messrs John Turnbull Jr. & Sons, Consulting Engineers, 18 Blythswood Sq. Glasgow, 20th February 1897," UGD 118/1/7/1, UGA.

[81] Sarah Fayen Scarlett, "The Craft of Industrial Patternmaking," *J. Mod. Craft* 4 (2011): 27–48.

[82] Harvey, *Early Days* (cit. n. 26), 60–1.

[83] Drawing dated 24 June 1857, UGD 202/0044, UGA.

[84] Drawing dated 24 December 1861, UGD 202/2148, UGA.

[85] Drawing dated 25 May 1862, UGD 202/1890, UGA.

[86] David McGee, "From Craftsmanship to Draftsmanship: Naval Architecture and the Three Traditions of Early Modern Design," *Tech. & Cult.* 40 (1999): 209–36; Jonathan Zeitlin, "Between Flexibility and Mass Production: Strategic Ambiguity and Selective Adaptation in the British Engineering Industry, 1830–1914," in *World of Possibilities: Flexibility and Mass Production in Western Industrialization*, ed. Charles F. Sabel and Zeitlin (New York, 1997), 241–72, on 247.

Glasgow companies even used their drawing offices' competence as a selling point, by advertising how little information they needed to issue a spare. "To request spare parts it is sufficient to give us the number of the centrifuge, which is inscribed in the vertical axis of each one," boasted Watson, Laidlaw & Co. in a brochure sent to the Spanish Caribbean in the 1920s and retained by a Puerto Rican factory. "We hold designs and plans of every centrifugal made by us, from the beginning of our firm in 1870 until the present, in order to be able to respond to any request for spares."[87] The drawing and pattern offices, no less than sugar factories or the shop floor, expose the constant process of maintenance and repair that underlay the surface of mechanically standardized sugar—a process that relied completely on the judgment, collaboration, and physical labor of human beings.

Glasgow's firms sought information about their products, and therefore about the state of sugar manufacture more generally, from across the Caribbean and the sugar-producing world. As such it may be tempting to think of the city's sugar workshops as something like Latourian centers of calculation, "mobilizing" and "accumulating" the world on paper through fixed inscriptions that travel easily.[88] In reality, however, these pieces of paper were severely recontextualized when they traveled, to borrow a term from the anthropologist Matthew Hull.[89] A tracing of a gear wheel meant one thing in Puerto Rico, next to the broken machine from which it was drawn. It meant quite another in Glasgow, amidst a company's ledgers and dimension books, patterns from the wheel's construction, and the metallurgical skills of its makers. Moreover, Glasgow's manufacturers were less central or coordinating than they were vulnerable, and their business depended completely on what they could learn from distant plantations.

Through the nineteenth century, sugar plantations were unquestionably where knowledge about sugar production would be generated. A century of production and maintenance by Glasgow's manufacturers enabled an industrial transformation in those plantations and in how sugar was made. At the turn of the twentieth century, that transformation began to enable claims that the Scottish city itself might generate knowledge about making sugar, just as the city's own importance began to waver.

MODEL FACTORIES

By the beginning of the twentieth century, the newest sugar factories in the world were many times larger than their predecessors of a few decades earlier. Glasgow firms were frequently called upon to design and construct these new, technologically sophisticated "central factories" from the ground up. The Harvey Engineering Company produced fourteen complete factories between 1905 and 1909 alone.[90]

[87] "Tenemos diseños y plantillas de todas la centrífugas fabricadas por nosotros desde la fundación de nuestra casa en 1870 hasta la fecha, así que podemos atender á cualquier pedido de repuestos." Watson, Laidlaw, & Co. catalog, "Centrifugas," in Colección Central Mercedita, caja "Católogos Comerciales 1920s–1940s," Archivo General de Puerto Rico, San Juan.

[88] Bruno Latour, *Science in Action: How to Follow Scientists and Engineers through Society* (Cambridge, Mass., 1987), 232–7.

[89] Matthew Hull, *Government of Paper: The Materiality of Bureaucracy in Urban Pakistan* (Berkeley and Los Angeles, 2012), 23–4.

[90] Harvey Engineering Company advertisement at the end of Llewellyn Jones and Frederic I. Scard, *The Manufacture of Cane Sugar* (London, 1909).

In the fall 1911 term, the Glasgow and West of Scotland Technical College (the descendant of the Mechanics' Institute) introduced a new post of lecturer in sugar manufacture, financed by "firms and individuals interested in this industry," including representatives of Glasgow's wealthy community of West India traders, estate owners, and commission merchants.[91] More than 75 percent of the financing for the lecturer's salary, however, was given by the city's sugar engineering firms, including the Harvey Engineering Company, Mirrlees Watson, A. & W. Smith, and Duncan Stewart.[92]

The centerpiece of the sugar school was a remarkable model of a sugar factory.[93] Mirrlees Watson provided a vacuum pan, Duncan Stewart delivered crystallizers, and Watson Laidlaw furnished its specialty centrifuges.[94] The college's 1913 annual report claimed that "the equipment for the demonstration of all the important processes in the treatment of sugar juice is now complete."[95] The first lecturer, a former West Indian factory chemist named Thomas Heriot, wrote in the *International Sugar Journal* in 1916 that the college had constructed a "complete factory in miniature" (fig. 4), one in which "every essential feature of the factory plant is reproduced on a smaller scale."[96]

Yet that emphatic sense of completion excluded crucial elements of the sugar factory. Most obviously, there was no possibility of a miniature mill for grinding sugarcane, which could not be brought to Glasgow before its juice hopelessly degraded. Similarly, neither the workers who would populate a real factory nor the ability to manage them were part of Heriot's miniature model. Commanding a workforce—"driving" them, in Heriot's word—"requires no technical skill, and may be better performed by others," rather than by the trained chemist or chemical engineer.[97] He acknowledged the importance of "administration" but felt it could be delegated to "native foremen" without much trouble.[98] And, finally, the machines were not subject to cycles of assembly and disassembly or heat and moisture that confronted actual factories in the tropics.

The Royal Technical College's model was derived from the products of machinery firms. Like the famous Phillips machine that modeled hydraulic Keynesianism, Heriot's miniatures represented the operations of a sugar factory as procedures subject to fine control.[99] With the help of the manufacturers and instrument makers, Heriot had

[91] Glasgow & West of Scotland Technical College (GWSTC) annual report 116th session (1912), p. 20, OE/4, Archives and Special Collections, University of Strathclyde Library. On the Audubon Sugar School in Baton Rouge, see John Alfred Heitmann, *The Modernization of the Louisiana Sugar Industry, 1830–1910* (Baton Rouge, La., 1987), chap. 10.

[92] GWSTC annual report 116th session (cit. n. 91), p. 64, University of Strathclyde Archives; Thomas H. P. Heriot, "Technical Training for the Sugar Industry," *Int. Sugar J.* 28 (1916): 173–9, n. 1. The salary for 1911 is found in OE/6/1/1, GWSTC staff card index, University of Strathclyde Archives.

[93] For models in general, see Soraya de Chadarevian and Nick Hopwood, eds., *Models: The Third Dimension of Science* (Stanford, Calif., 2004).

[94] This information comes from the GWSTC annual reports for 1912 and 1913; I was unable to find entries for these donations in the relevant books of the various companies.

[95] GWSTC annual report 117th session (1913), p. 24, OE/4, University of Strathclyde Archives.

[96] Heriot, "Technical Training" (cit. n. 92), 175–6.

[97] Thomas Hawkins Percy Heriot, *Science in Sugar Production: An Introduction to Methods of Chemical Control* (Altrincham, 1907), 7.

[98] Heriot, "Technical Training" (cit. n. 92), 178.

[99] Mary S. Morgan and Marcel Boumans, "Secrets Hidden by Two-Dimensionality: The Economy as a Hydraulic Machine," in de Chadarevian and Hopwood, *Models* (cit. n. 93), 369–401, esp. 392.

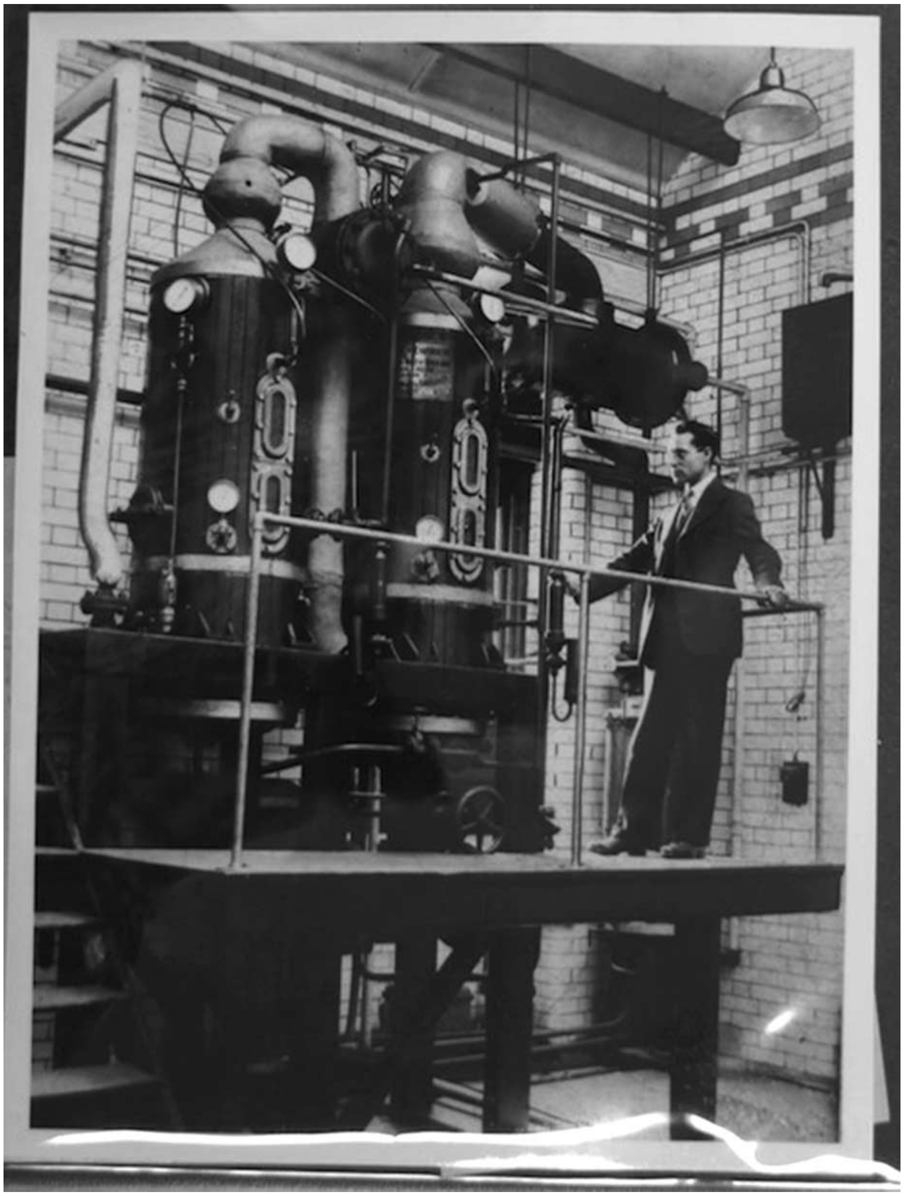

Figure 4. *Evaporator, School of Sugar Manufacture, Glasgow and West of Scotland Technical College, c. 1930, OP4/145, Archives and Special Collections, University of Strathclyde Library*.

installed "conveniences for exact experimental work which are lacking in the sugar factory," which allowed him to educate students "*in a more direct manner than by practical experience*."[100] He intended that an enrollee in the sugar manufacturing course would learn "all essential principles outside the factory, by means of lectures and laboratory experiments, so that, when he first enters the factory, he understands

[100] Heriot, "Technical Training" (cit. n. 92), 173; emphasis added.

what he sees, and needs no other instructor than his own eyes and intelligence."[101] In other words, Heriot claimed that his school was in fact superior to any actual factory for learning about sugar production.

And students came, first from the engineering companies themselves. The evening course was packed with almost sixty employees of the local sugar machinery works. They heard lectures that followed sugar from its agricultural beginnings as "raw material" through milling, diffusion, clarification, concentration to syrup, crystallization, drying, and packing, all before "chemical control of manufacture." Within a few years, the school added a new laboratory course that included "analysis of sugars, juices, &c."[102]

The course began as a way to teach local sugar-machinery-making students how factories worked, but it became a model of a factory that taught colonials how their factories were supposed to work. Over the next decade, the college reported that its enrollment shifted to include many more West Indian students, who came in the hope "that their work [here] will do much to increase the knowledge of modern methods of sugar production and manufacture *which they have come to this country to acquire*."[103] For a hundred years, the infrastructure of sugar production had been characterized by just the opposite flows of people, paper, and knowledge. Glasgow's own success at industrializing the production of sugar had led to institutions like the "factory in miniature" at the city's engineering college.

It also set the stage for Glasgow's undoing, as rival centers of sugar-production expertise could emerge. A 1901 survey of "Local Industries of Glasgow and the West of Scotland" painted a gloomy picture of the future of the sugar-machinery industry. The British West Indian sugar market had run dry, though this was partly compensated by sales to independent Latin American nations, and to imperial possessions in South Africa, India, and Queensland. The real concern for the Glasgow sugar machinery makers was being shut out of two of the largest and richest sugar producers in the world. A quarter century earlier, after the Kingdom of Hawai'i signed a reciprocity treaty with Washington in 1876, Glasgow had supplied the islands with their first "complete" sugar factory. But the archipelago, "once a good market, is now practically closed to British manufactures." Fortunately, Cuba was "showing signs of revival, and may yet prove a fairly good market," according to the survey, "if it is not turned into an American preserve in a similar way to Honolulu."[104]

Far more than a "preserve," the Hawaiian capital would soon become home to the most advanced sugar-machinery firm in the world. The Honolulu Iron Works had been founded in 1853 by David Weston, who sold foreign rights to his patent for a self-stabilizing centrifuge to Mirrlees Watson. Like so many of Glasgow's firms, the Iron Works began by repairing others' machinery. By the 1880s, however, its work was

[101] Thomas H. P. Heriot, "The Sugar Industry after the War," *Proc. Roy. Phil. Soc. Glasgow* 49 (1918): 31–44, on 31.

[102] E10/2/6, "Guide to Evening Classes in Science and Technology," 1912–3, 29, 55, University of Strathclyde Archives.

[103] GWSTC annual report 116th session (cit. n. 91), 20; E10/2/2, Glasgow & West of Scotland Technical College Prospectus of Day Classes 1911–2, University of Strathclyde Archives; emphasis added.

[104] William G. Hall, "The Future of Sugar Is in the Orient," *Trans Pacific* (September 1921), 57–60, on 59; Henry Dyer, "Mechanical Engineering," in *Local Industries of Glasgow and the West of Scotland*, ed. Angus McLean (Glasgow, 1901), 35–91, on 64.

in high demand, "especially since the great distance from manufacturers in America and Europe made it extremely necessary to obtain what was needed right at home."[105] Honolulu Iron Works profited from the creation of the Hawaiian Islands as a model sugar production zone, free from the historical labor constraints that had plagued planters in the Caribbean. In this sense it was a scaled-up version of Heriot's "complete factory in miniature," complete not despite its lack of skilled labor but because of it.

The status of Glasgow as the world's dominant heavy-engineering city diminished in realms beyond sugar machines. Following the boom of the Great War, when many sugar-machinery makers retooled for armaments, the crop of 1920 brought the highest sugar prices in a century. Mountains of unfilled orders rose in the sales offices of sugar engineering companies, and so did profits. But those lucrative harvests were temporary, merely filling the vacuum left by European beet sugar. When the beet crop returned in 1921, prices collapsed.

Moreover, in return for tariff reciprocity with sugar producers, American protectionism had led to an increase in the relative cost of Scottish machinery. New factories were constructed in Cuba and the Hawaiian archipelago, demanding new machinery, because sugar from those islands could now enter the United States tax-free. But now American machinery faced no taxes upon entering the islands either. British manufacturers hoped this tariff surcharge would not entirely outweigh their firms' long-standing relationships with engineers and owners. But as Cuba's central factories failed following the 1921 collapse, they often fell into the hands of American creditors, who strongly preferred to buy from domestic engineering firms. That year, only a single order of centrifugals arrived in Scotland. Glasgow newspapers now reported on their city's sugar firms in different tones: they spoke of "moderate activity," business that was "fairly active," with "work not so plentiful as in the years past." Some firms received no new contracts until 1923.[106]

By the 1920s, by contrast, the Honolulu Iron Works were producing factories for Cuba, the Dominican Republic, Formosa, and the Philippines. The firm boasted not only a branch in New York City but a full office in Havana, including engineering staff—a far more substantial presence than the consulting engineers on whom Glasgow firms had historically relied, and one that gave customers the possibility of far closer coordination. Technology, expertise, and individuals could move through multiple overlapping circuits of the sugar economy. If it remains strange to think of sugar expertise in sugar-free Glasgow, it should be no less discordant to our received geographies of technology, knowledge, and capitalism to find a prestigious ironworks in the Hawaiian Islands—an archipelago entirely lacking in useful ores.[107]

In 1921, the manager of the Honolulu Iron Works published an article in a trade journal called *The Trans Pacific*, and with industry as well as agriculture in mind, titled it "The Future of Sugar Is in the Orient."[108] That same year, the board of A. & W. Smith dispatched the aptly named Martin Ironside to Cuba "for the purpose of

[105] Hall, "Future of Sugar" (cit. n. 104), 59.
[106] D. Bradley, "Fletcher & Stewart Ltd: A Business History" (MPhil thesis, Univ. of Nottingham, 1972), 118, 122, 211, UGD 118/11/1/48, UGA.
[107] "Ancient Hawaiians: Plenty of Oars but No Ores," U.S. Geological Survey Hawaiian Volcano Observatory, 24 September 2009, https://volcanoes.usgs.gov/observatories/hvo/hvo_volcano_watch.html?vwid=359 (accessed 17 April 2018).
[108] Hall, "Future of Sugar" (cit. n. 104).

gaining knowledge of the most modern practice" in sugar making and in machinery. They judged that "such a visit would be advantageous" to the firm and, perhaps acknowledging the usefulness of Honolulu Iron Works' Havana office, "a similar visit on the part of a member of the Works Staff would be even more so." Ironside returned six months later, having toured not just "the Sugar Factories of Cuba" but also Trinidad, Louisiana, and elsewhere in the United States.[109] He may well have visited Louisiana's new and "radical" Adeline Sugar Factory, which had been "designed in its entirety by the Honolulu Iron Works Company of New York"—a company name that concisely expresses the geographic inversions of expertise in the early twentieth-century sugar economy.[110]

CONCLUSION

The geography of the cane sugar economy placed singular demands on the companies in Glasgow that built machines for that economy in Glasgow. Machines for milling grain into flour or for spinning cotton into thread, to name a few other creations of Glasgow industries, only had to travel as far as other British cities. Sugar machines, by contrast, spent their lives in tropical factories, where they could work close to the plant itself and to its agriculture. They had to be durable yet flexible, customized yet interoperable. They had to function for decades without intervention from their manufacturers yet be immediately recognizable to those manufacturers when they were called upon to make repairs. They also had to provide the infrastructure for the precise chemical and human operations that turned the sugarcane plant into sugar—a substance that, by the twentieth century, appeared to approximate the ideal commodity as closely as any natural object could.

That superficial appearance of an efficient commodity market belied the difficult and constant work deep below. Sugar plantations and factories famously required the adaptive skills of the people who worked within them. So too, this essay has shown, did the workshops that built the machines on which those plantations and factories depended. Glasgow's sugar engineering firms depended on peregrinations of specific people to carry information and knowledge that paper could not convey and to reassemble machines in ways that were not self-evident. They nonetheless relied on movements of idiosyncratic inscriptions—from tracings made directly from broken machines to patterns within the works itself—to build new machines and learn the status of their old ones. Meanwhile, on the other side of the Atlantic, clients used a firm's management of those inscriptions to test its ability to supply real products when they would be needed most.

Despite their distance from the sources of sugar and of knowledge about it, Glasgow's firms successfully managed these fragile networks for much of the nineteenth century. Their success meant they played a crucial role in industrializing sugar production in the Caribbean and across the world. That industrialization, however, and the reconfiguration of sugar making around modern science, had unexpected consequences for both Glasgow and the tropics. First, if sugar production were now a matter of machines, then it became plausible for someone like Heriot to claim that a model

[109] A. & W. Smith Minute Book no. 2, 24 October 1921 and 3 May 1922, UGD 118 1/1/1, UGA.
[110] "The Adeline Sugar Factory," *American Sugar Industry and Beet Sugar Gazette* 14 (1912): 36.

factory was complete if it included nothing but machines. Second, plantations in the Hawaiian Islands were constructed as a model of what fully industrialized sugar production might look like. Helped by tariffs and proximity, the Honolulu Iron Works became the leading manufacturer not only in its own archipelago but for much of the world.

The exclusion of Glasgow from histories of the sugar world has led to neglect of the close connections between the standardization of commodities and the variety of tools and techniques that make commodification possible. Precisely because of the distance and fragility of sugar's networks, and because of the immense reaches of time and space that sugar machines needed to cross, such machines make those connections visible.