A Clinical Construct: Research, Experimentation, and Education at the Johns Hopkins Hospital

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ABSTRACT

Background: The Johns Hopkins Hospital, the first U.S. institution to integrate medical education with practice, has served as a critical case study in understanding the evolution of American medical institutions in response to advancements in medical science, education, and technology. However, the role of architecture and design in informing those institutional practices has not been sufficiently explored.

Aim: This study examines the intricate interplay between architecture and medicine in the late nineteenth century through a historical analysis of the design, construction, and early operation of the Johns Hopkins Hospital in Baltimore, focusing on how this interdisciplinary relationship shaped both the hospital's physical environment and institutional practices.

Methods: This paper utilizes historical analysis to investigate the design, construction, and operations of the Johns Hopkins Hospital. By examining primary archival materials, it details how architectural strategies addressed scientific, technological, and educational advancements.

Results: The investigation reveals that the hospital's architecture not only facilitated medical research, experimentation, and education but also embodied a novel blend of scientific inquiry and architectural design.

Conclusions: The Johns Hopkins Hospital exemplifies the transformative potential of integrating architectural design with medical science. This case study underscores the enduring significance of interdisciplinary collaboration, offering insights into contemporary practices and the future of hospital design and medical education and practice in academic communities.

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While *medicine* and the *hospital* are virtually synonymous today, the confluence of the two embodies a relationship that has significantly evolved over centuries. Historically, the two occupied uniquely distinct domains that, while occasionally interacted, rarely overlapped. The emergence of the hospital as a modern medical institution in the eighteenth century was a product of sociopolitical and epistemological transformations during the Enlightenment that redefined medicine as scientific knowledge and the hospital as a charitable public institution (Foucault, 1976). With the growing demand for medical care, the introduction of new building technologies, and advancements in medical research and education in the nineteenth century, hospitals began to increasingly merge architectural innovations with modern scientific practices.

As the first U.S. institution to integrate medical education with practice, the Johns Hopkins Hospital in Baltimore is a model of this transformative era (Figure 1).

Figure 1

"Front View of Buildings from Northeast"

Note. Photographed by Frederick Gutekunst in 1889, this image shows the Administration Building and the two Pay Wards facing Broadway, John Shaw Billings, *Description of the Johns Hopkins Hospital* (Baltimore: The Johns Hopkins Hospital, 1890), Plate 1.

Completed in 1889, it exemplifies how the disciplinary techniques for medical observation, experimentation, and education became deeply intertwined with the institution's architecture. The design and construction, led by a physician and assisted by an architect, reveal the dynamic interaction and professional rivalry between medicine and architecture at a time when both were in the early stages of professionalization and in a subject in which both claimed expertise. Influenced by the advent of laboratory medicine, the hospital was conceived as a full-scale architectural experiment, where the buildings themselves functioned as didactic instruments to demonstrate the practical application of medical theories to architectural design and the consolidation of sanitation and hygiene principles with building technology.

This paper explores the design, construction, and early operation of the Johns Hopkins Hospital, highlighting its pivotal role in the symbiotic relationship between architecture and medicine in the late nineteenth century. This examination reveals how the evolution of the medical hospital, as a modern institution, necessitated the intervention of an architectural paradigm that not only accommodated but also propelled this transformation. Through a historical analysis of archival material, the paper illustrates how architectural innovation was deeply intertwined with the era's scientific and technological transformations. In doing so, the study underscores the importance of interdisciplinary collaborations and dialogue between architecture and medicine in order to not only improve human experience but also instigate innovation in research, experimentation, and education in both fields.

DESIGN AS A RESEARCH PROJECT

In a letter on March 10, 1873, shortly before his death, Baltimore businessman and philanthropist Johns Hopkins instructed his trustees to build a hospital in connection to the medical school of his university that would "compare favorably with any other institution of like character in this country or in Europe" (Hopkins, 1873). The trustees formed a Building Committee and spent the following year consulting the literature, visiting various hospitals, and debating how to approach the project. While they initially hired an architect, John R. Niernsée, the Building Committee remained ambivalent, viewing the design and construction of the hospital as a "technical scientific question" that required medical knowledge and expertise (Johns Hopkins Hospital, Board of Trustees, 1874). The trustees then sought the suggestion and advice of "five distinguished physicians," and ultimately appointed one of them, John Shaw Billings, Assistant Surgeon in the U.S. Army, as a "Medical Advisor" to the Board. They charged Billings to lead the design and construction of the Hospital and asked their architect, "to prepare his plans in consultation with and under the supervision of a surgeon who is a recognized authority in hospital construction" (Architects in Public Employ, 1877).

Throughout the nineteenth century, the perceived correlation between environmental conditions and disease incidence in hospitals had elevated the design authority of doctors over that of architects. In fact, the majority of early American hospitals—including the Pennsylvania Hospital (1752) and the Commercial Hospital in Cincinnati (1852)—were designed by doctors and hospital administrators with little or no input from architects (Kisacky, 2017, pp. 78-79). Meanwhile, by the 1870s, medical science was in the midst of an epistemic transition. Challenging the basic assumptions of the miasma theory, which suggested that diseases are caused by noxious forms of "bad air" or effluvia (i.e., vapors emanating from rotting organic matter), the germ theory of disease maintained that diseases are caused by minute living particles or microscopic organisms. Advances in bacteriology in Europe through the work of John Snow, Louis Pasteur, and Joseph Lister had provided evidence that "hospital diseases" and their high mortality rates, known as "hospitalism," were not a product of its architecture or poor ventilation but the unsanitary medical practices (Lister, 1867).

While the medical community in the United States was aware of these advances, most still considered microorganisms to be atmospheric entities that floated in the air (Lister, 1875). The focus, therefore, simply shifted from invisible and immaterial influences like miasma or effluvia to microscopic material agents such as germs, particles, or disease dust (Tomes, 1998; Kisacky, 2017). As a result, much of the old sanitary science was reappropriated to the new germ theory, and ventilation continued to be viewed as the foremost cause and cure of disease. Like most of his American peers at the time, Billings considered both theories to be true (Gariepy, 1994). He considered germs to be particularly resilient creatures, able to withstand cold or dry conditions, and even resist common cleaning agents. For him, the most effective solution was to apply an “ounce of prevention” through systematic classification and separation of patients, and a complete isolation of contagious or dangerous cases (Billings, 1875). To that end, he proposed that the wards be totally separated and totally disconnected from each other, with at least fifty to a hundred feet of space.

This form of spatial separation and classification had already been discussed and debated by doctors and architects since the eighteenth century, materializing in the form of an architectural typology known as the *pavilion plan*. In the mid-nineteenth century, the pavilion plan gained wider acceptance for its organizational and therapeutic merits, largely due to English nurse and social reformer Florence Nightingale’s endorsement in her influential book, *Notes on Hospitals* (Nightingale, 1859). Conceiving the hospital as a series of low-rise detached buildings evenly spaced across a large open ground, the pavilion plan aimed to distribute the patients in separate wards to minimize the spread of disease (prevention) and maximize the exposure to natural light and air (cure). While the pavilion plan existed long before Nightingale, her book systematized the existing knowledge by transforming the loosely defined guidelines into a codified and standardized hospital design manual populated with charts and statistics. The pavilion plan was presented as an all-encompassing universal hospital architecture, adaptable to different scales, sites, climates, cultures, and countries. Fueled by a global anxiety around disease and the political and economic ambitions of the colonial era, and powered by the technologies of printing, transportation, and communication, pavilion plan principles were exported across the colonial world, establishing itself as the universal architecture of the hospital (Taylor, 1997).

While not particularly enthusiastic about the pavilion plan, Billings saw the essential feature of the hospital as its ability to minimize exposure to infection and reduce the spread of disease (Billings, 1875). To that end, he saw the spatial arrangement of the hospital—whether a pavilion or a military barrack plan—as a potential instrument of aerial separation, isolation, and therefore disease prevention. Billings believed that the cardinal principle in hospital design and construction was “to do as little harm as possible” (Billings, 1889a). The separation of structures and ventilation of wards, therefore, functioned not so much as a means of cure, but as a means of aerial and bacterial containment. For Billings, this would require a “careful classification of the patients, by a methodical system of isolation, and by destruction of the causes of disease as they occur” (Billings, 1875).

Unlike an architect, Billings's approach toward the design of the Hospital was a direct application of the *scientific method* to architecture (Fair, 2014). He spent the first few months researching current practices and surveying the field based on literature reviews and visits to existing American hospitals. He then took a three-month-long leave of absence to visit hospitals and medical schools across Europe (Billings, 1876). He also met and corresponded with scientists and those he considered experts on hospital design, including Joseph Lister, Thomas Henry Huxley, and Florence Nightingale (Cope, 1957). He carefully documented his observations and the feedback he received. Upon returning from his grand tour, Billings shared the valuable information and feedback he obtained during that trip but reported that he “did not find it possible to obtain positive reliable data as to the effects of various plans of Hospital construction or ventilation” (Billings, 1877, p.5).

The introduction and availability of new systems of mechanical heating and forced ventilation during this period had provided new means, but also further complicated the design of hospitals (Bruegmann, 1978). There were three methods of ventilation: the natural method, ventilation by aspiration, and ventilation by propulsion, as well as the possibility of using a combination of two or all three of those methods. In addition to ventilation, Billings was also weighing the choice between heating by hot water or by steam. To settle the “vexed question of heating and ventilation," Billings relied on a series of experiments conducted at his request in two hospitals in Boston and in Washington D.C., carefully monitoring the heating and ventilation performance to gather what he termed "positive data." He hoped that the results of these experiments would reveal the merits of different methods of heating and ventilation in hospitals "with a fair degree of scientific precision." While the result of these experiments provided much valuable data, the varied condition of the hospitals revealed discrepancies and inconsistent results. He argued that a year-long collection of data from various hospitals could provide substantial insights for a valuable treatise on hospital heating and ventilation (Billings, 1878).

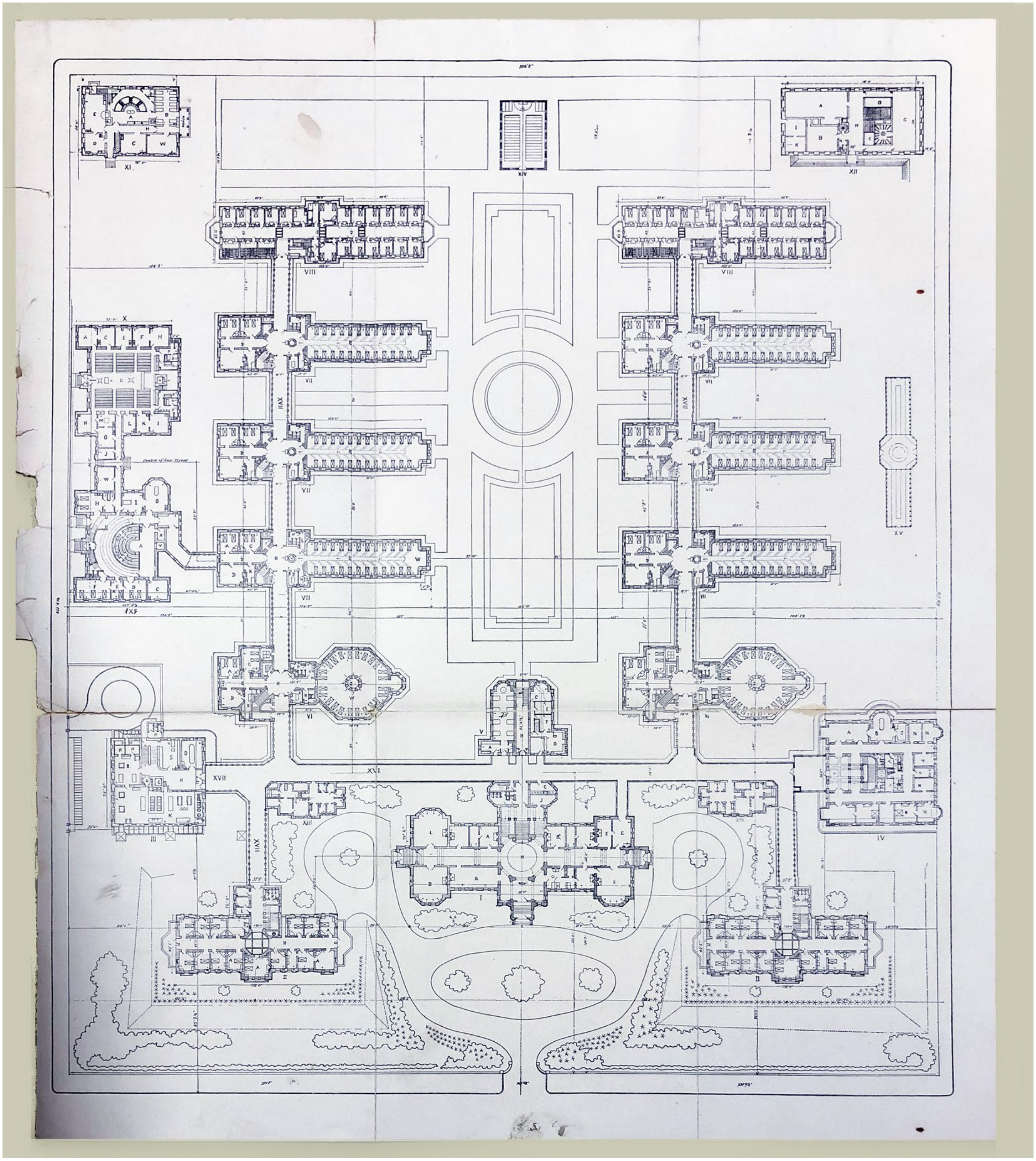
PLAN AS AN EXPERIMENTAL SYSTEM

A detailed study of heating and ventilation at a national scale, however, was not available to him. Unable to obtain any reliable data, Billings opted to use the final constructed buildings at the Johns Hopkins Hospital as a full-scale experiment, "a sort of laboratory for heating and ventilation." In his report, Billings justified this experimental approach as an epistemological, pedagogical, economic, and even moral imperative—one that less-endowed institutions could not afford to carry out. Billings then utilized the pavilion system as a set of independent variables for an architectural experiment. He recommended using varied systems of heating and ventilation in the wards and "not employing any one system alone at first," in order to "compare steam with hot-water heating, to determine the velocity of water at different temperatures, to compare ventilation by aspiration with that by propulsion, or by upward currents with those drawn downward" (Billings, 1889a). In addition to heating and ventilation systems, Billings also used different building designs as experimental variables. Rather than a standard Nightingale pavilion, his plan for the Hospital included variations in form, size, and interior layout. Even the seemingly identical Common Wards were equipped with different ventilation systems to allow them to be studied in isolation.

The culmination of Billings's research, fieldwork, and experimentations was the development of a hypothesis that manifested itself in the final Block Plan of the Johns Hopkins Hospital in 1878 (Figure 2). The plan was an assortment of all the architectural variables he had studied and considered: permanent structures and temporary tents, one- and two-story buildings, rectangular and octagonal pavilions, private rooms and open wards, heating by water and by steam, and ventilation by natural means, by aspiration and by propulsion. He postulated that through careful comparisons and observation of the buildings' performance, reliable data might be obtained which would enable the Hospital to make "most important contributions" to the "knowledge of Hospital hygiene" (Billings, 1878). These controlled architectural variations, along with meticulous record-keeping, were intended to enable Billings to empirically correlate environmental conditions with disease incidence to identify the most effective design.

Figure 2

"General Block Plan of the Hospital"



Note. Photographed in 1877, The Alan Mason Chesney Medical Archive, The Johns Hopkins Medical Institutions.

But the ultimate measure for the experiment was not just temperature or human comfort, but health and recovery. Therefore, to narrow the range of the architectural and the environmental independent variables of the experiment, Billings also had to rely on an experimental group that was otherwise impossible to simulate in a laboratory model: the presence of living patients and the continuous observation of their health over a long period of time. The use of hospital patients as clinical, teaching, or research material was also not unusual in the nineteenth century. As medical education increasingly emphasized clinical experience, hospitals offered doctors and medical students an adequate supply of clinical material for research and experimentation. And these experimental treatments in the hospital had allowed doctors to consolidate their professional authority (Forty, 1980). However, those who submitted to medical education or experimentation were not the private patients, who paid for their treatments, but patients who were admitted without charge who tacitly paid for their treatment by serving as a clinical material (Kisacky, 2017).

Upon submitting revised plans with his fourth report, Billings expressed that while he couldn't assert that the plans were the best possible, he believed they met Hopkins's expectations, satisfying the needs of physicians, hygienists, architects, educators, and investigators. He deferred to the Trustees on the financial viability of the project. The Board approved the plans on February 20, 1877, prompting detailed drawings from Niernsée and construction commencement in April. Financing the construction of the hospital buildings, however, proved to be challenging. Hopkins, in his will and letters, allocated approximately seven million dollars, divided equally between the hospital and university (Hopkins, 1873). For construction and maintenance, he earmarked bank stocks, real estate, and his Clifton estate, predicting an annual revenue of $120,000. He instructed that, should he pass before their completion, the income should be used to finish the hospital and orphanage. Billings, acknowledging the guiding principles, warned of high costs in his initial report on July 15, 1876. He estimated $1,200,000 for construction, indicating a multi-year funding and building phase. Francis T. King, the Board President, and the trustees faced the challenge of aligning construction with the trust's annual income. Cost increases and reduced endowment returns (from $234,022.27 in 1876 to $191,364.23 in 1881), along with Billings' demands for medical facilities, delayed the project (Chesney, 1943). Despite considering an early partial opening, the construction, which was supposed to take four years, spanned twelve. The hospital, opening on May 7, 1889, operated with only half of the wards completed. Billings later referred to the constructed block plan as provisional, maintaining that the administrative and service buildings would suffice upon full completion (Billings, 1890)—a state unrealized as the southern pavilions remained unbuilt.

Throughout the design process, the plans of the Hospital were continually presented, modified, and re-presented as a set of variables: temporary or permanent, wood or brick, one or two stories, twelve or sixteen pavilions, classified by patients or diseases, heated by steam or water, ventilated naturally or mechanically, built at once or in phases, and so on. This condition of the plan, as a set of autonomous components, was the most consequential aspect in the design, construction, and later operation of the Johns Hopkins Hospital that transformed the pavilion plan from an architectural proposition into an institutional system that operated through architecture. This approach toward the plan, as a provisional kit of parts or a *system*, enabled the isolation and abstraction of specific components or conditions of its architecture, allowing them to become subject to independent scientific study and analysis.

BUILDING AS A DIDACTIC INSTRUMENT

When Johns Hopkins formed The Johns Hopkins Hospital and The Johns Hopkins University as two separate corporations in 1867, he divided his assets, about seven million dollars in total, equally between the two institutions

(Chesney, 1943). In his 1873 letter of instruction to the trustees of the Hospital, Hopkins expressed his wish that "the institution shall ultimately form a part of the Medical School of that University for which I have made ample provision by my will" (Hopkins, 1873). The statement in Hopkins's letter constituted the charter of the School of Medicine as a part of the Hospital, legitimizing the existence of such a school within the University, and ensuring that the School would have continuous access to the Hospital facilities. Through this unprecedented institutional alliance, the Johns Hopkins Hospital became the first institution in the United States to combine higher medical education with practice.

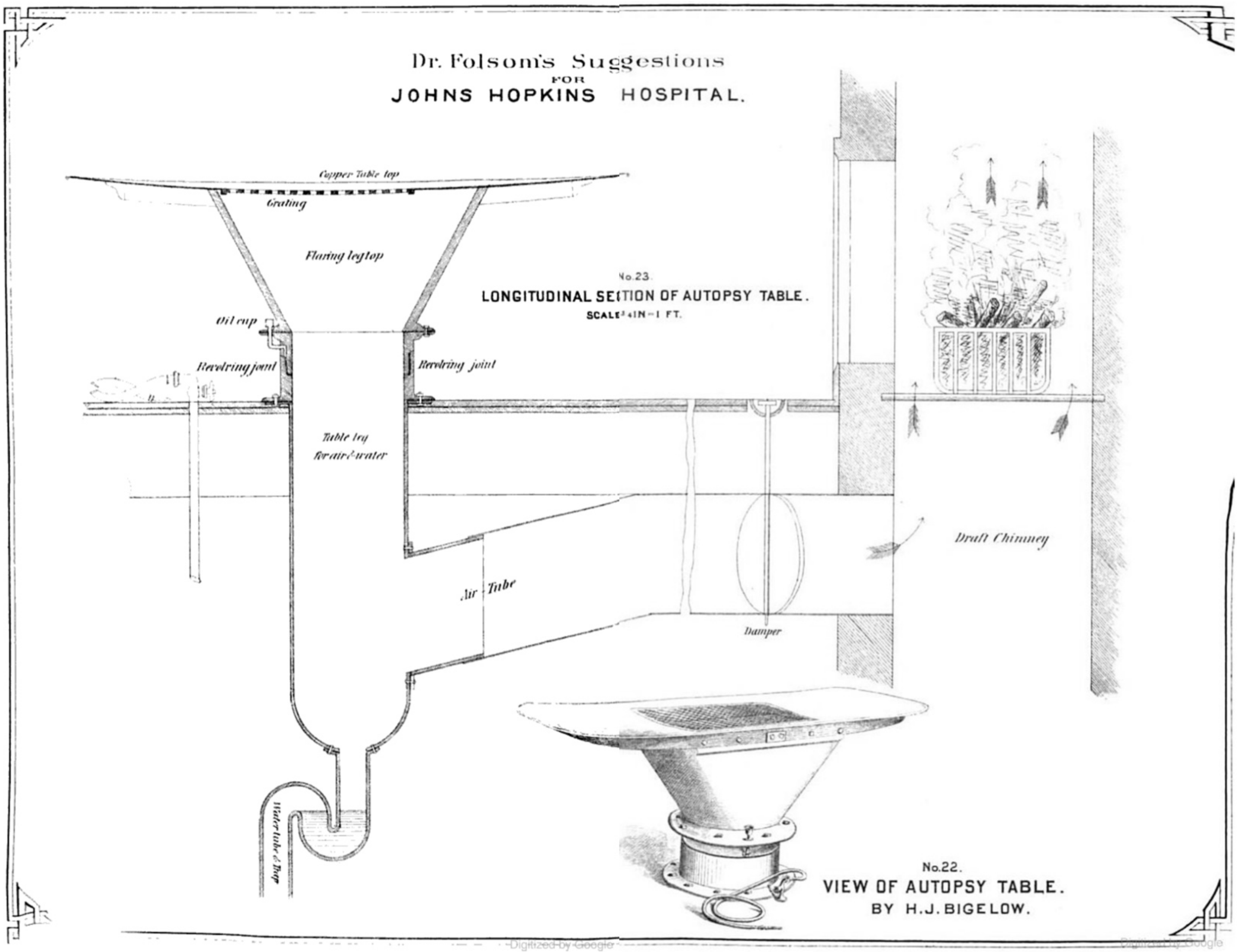
Billings had recognized the opportunities the union of the two institutions could afford and saw the Hospital as an "instrument of medical education." In the opening paragraph of his 1875 essay proposal, Billings emphasized Hopkins's original mandates for the Hospital to "properly care for the sick poor" and "aid in the education of Physicians and Nurses," but he argued that the institution should have a third objective, "to promote discoveries in the science and art of medicine, and to make these known for the general good." To that end, Billings saw the Hospital primarily as an experimental work—a laboratory that would reveal new forms of knowledge about the transmission or treatment of disease, medical practices, research and education, and function as an institutional mechanism "to increase and diffuse knowledge" (Billings, 1875).

The nineteenth century saw the transformation of medicine from scholastic practice that relied on classical texts, theoretical or narrative cues, to a modern science that operated based on clinical observation, physical examination, and anatomical evidence. This shift was instigated in part by the growing interest in the practice of autopsy and dissection in the late eighteenth century, which, by the turn of the nineteenth century, began to interpret anatomical changes in relation to disease. Through the work of Marie-François-Xavier Bichat and others, diseases were no longer seen as a general impairment of the entire organ but rather as a local injury to one of an organ's several tissues. The growing interest in physical examination and the anatomical localization of pathology led to the emergence of what has been referred to as an anatomical perspective. A visible impact of this epistemological and pedagogical shift in medicine was the emergence of anatomical and operating theaters—where bodies were laid bare, observed, examined, dissected, and exposed—as the locus of medical knowledge and instruction.

At the Johns Hopkins Hospital, the institution's heterogeneous identity made the surgical and anatomical theaters ever more charged. The Amphitheater, for instance, designed specifically for the use of students, was equipped with perforated seats over steam heating coils to enhance heating and ventilation. Similarly, the Dispensary's waiting area utilized benches equipped with special air registers for "fresh warm air" that seamlessly blended architectural elements with mechanical systems (Billings, 1890). The most notable innovation was found in the Pathological Building's autopsy theater, where a custom-designed autopsy table featured an integrated ventilation and plumbing system (Figure 3). These design choices at the Johns Hopkins Hospital embody the fusion of architecture and furniture with medical technology and engineering.

Figure 3

Norton Folsom, "View of Autopsy Table by H. J. Bigelow"



Note. Hospital plans: Five Essays Relating to the Construction, Organization & Management of Hospitals, Contributed by Their Authors for the Use of the Johns Hopkins Hospital of Baltimore, 1875.

The integration of advanced building systems into architectural design marked a significant evolution in the construction of medical facilities, addressing previous challenges such as ventilation concerns, and the architect-engineer dynamic. By the 1870s, these issues had largely been overcome through the standardization of technology, making sophisticated heating and ventilation systems accessible to architects, engineers, and the broader public through various publications. This new building technology transformed the nature of various building types that largely depended on central heating and forced ventilation—such as prisons, theatres, greenhouses, and hospitals—and increased comfort and safety in others. The most profound change, as some historians have observed, was the reconceptualization of the building itself as "living organisms or machines," tasked with enclosing and servicing an interior atmosphere (Bruegmann, 1978). While Billings too viewed the Hospital as a living organism, it was not the buildings alone but the institution as a whole—the buildings and their systems, the patients, the staff, and the environment they all shared—that was akin to a living and functioning body (Billings, 1889a).

This unique conceptual approach towards architecture was embodied in the design of the Johns Hopkins Hospital. The introduction of building systems and equipment in the nineteenth century posed new design challenges, and architects went to great expense to conceal the pipes and ducts in their buildings (Bruegmann, 1978). Much like the body's internal organs and physiological systems, the building's pipes, ducts, and wires remained largely invisible, hidden and internalized within the wall cavities, or tucked away in the basement or the attic. And well into the twentieth century, chimneys and ventilation shafts were the only mechanical elements that escaped the building's interior cavities and appeared on the exterior (Kisacky, 2014). However, unlike most architects during this period, who concealed mechanical components or even engaged with building technology in their design through their formal integration with architectural design, Billings was interested in the functional consolidation of the two domains. From the rounded corners, ridged ceilings, and perforated floors to the self-closing doors and ventilated seats, he saw the architecture of the Hospital as a single organized body, a pneumatic and atmospheric machine, where architectural and engineering requirements are consolidated and resolved through design (Figure 4). "Buildings and machinery" Billings noted in his address at the opening of the Hospital, "are only means to an end, tools which must be handled by skilled workmen to produce the desired result" (Billings, 1889a).

Figure 4

"Octagon Ward, Interior View"

Note. Photographed by Frederick Gutekunst in 1889, John Shaw Billings, Description of the Johns Hopkins Hospital (Baltimore: The Johns Hopkins Hospital, 1890), Plate 19.

What further distinguished Billings's approach in the expression of building systems was his commitment to the educational mandate of the institution. Beyond a functional and spatial container, or even an experimental object, Billings saw the architecture of the Hospital as an instructional device, a "great laboratory" for both medical and architectural education (Billings, 1889b):

> Many of the arrangements of the hospital have been constructed with reference to this instruction; it is a great laboratory for teaching the practical applications of the laws of hygiene to heating, ventilation, house drainage, and other sanitary matters. All pipes and traps are either exposed to view or can be seen by merely opening a door, and in the tunnel beneath the corridor you can study at your leisure the complicated and yet simple arrangement of pipes for gas, steam, water, sewage, etc., which are usually buried and remain a profound mystery to every one except the plumber, and often puzzle even him.

Therefore, it wasn't just the numerous ventilating shafts and chimneys in the exterior, but all the pipes, ducts, traps, and apparatuses on the interior that were exposed to view and accessible for observation and study. The Hospital's pamphlet guide, printed for the opening of the Hospital, described each building in a few sentences, often focusing exclusively on the heating and ventilation systems, even instructing the visitors to "note mixing valves in walls at head of beds for regulating temperature of fresh air supply without interfering with quantity" (Johns Hopkins Hospital, 1889). In this way, Billings conceived the Hospital as a giant laboratory, an anatomical theater, where the internal building systems were now laid bare and exposed, not only for observation and adjustment, but also for the purpose of architectural instruction and education.

The desire for experimentation was fueled by the rise of the laboratory and experimental medicine in Europe. The laboratory revolution during this period emerged in Germany, and spread to the United States through American physicians who were educated there or influenced by German practices. The most influential of these physicians were a group known as the "big four"—including William Henry Welch, William Stewart Halsted, William Osler, and Howard Kelly—who came together at the Johns Hopkins Hospital and Medical School to establish new models of medical education and practice (Acherknecht, 2016). The introduction of residency, fellowship, and internship programs, as well as the integration of ward-work or principles of clinical clerkships, and grand rounds, into the curriculum were among the new educational methods that shifted medical education away from the textbooks and lecture halls towards the hospital wards and around the patients' beds (Figure 5).

Figure 5

"William Osler Conducting Clinic in the Surgical Amphitheater"

Note. The Johns Hopkins Hospital, circa 1900, The Alan Mason Chesney Medical Archive, The Johns Hopkins Medical Institutions.

Meanwhile, the consolidation of medical knowledge was also instrumental in that process. Billings in particular is credited in playing a key role in "the stimulation of American medical scholarship" (Acherknecht, 2016). He founded the Surgeon General's Library, which became known as "the greatest medical library in the world," developed two medical bibliographical tools—the Index Catalog of the Surgeon General's Library (now the National Library of Medicine) and the Quarterly Indexes—but also was deeply involved in the planning and organization of the Johns Hopkins University Medical School. "It is in this work of discovery," Billings noted in his address at the opening of the Hospital, "that it is hoped that this hospital will join hands with the university, and it is in this hope that some of the structures around you have been planned and provided" (Billings, 1889b). The stricter educational standards in institutions like the Johns Hopkins along with stricter licensing procedures and professional practice established by the American Medical Association, marked the beginning of what is now referred to as a revolution in American medicine (Acherknecht, 2016).

Beyond its own educational function within the buildings, the complex heating and ventilation system of the Hospital also informed the education and training of the staff. The intricate system of heating and ventilation in the Hospital, along with the various methods of environmental control, required regular manipulation and adjustment of apparatus and instruments. Within each ward, for instance, there were about forty-four valves operating the registers and vents that controlled the delicate circulation of air, its quantity, velocity, pattern of movement, or temperature. To maintain both environmental and disciplinary control, Billings had charged the Hospital nursing staff with the responsibility of operating the heating and ventilation apparatus. To that end, the Hospital nurses were trained to attend both "the apparatus and the patients" (Billings, 1875, p. 4). Additionally, they were responsible for keeping hourly records of temperature, humidity, and air pressure using special proformas (Fair, 2014, p. 372).

This required responsibility was reflected in the educational curriculum of the nurses at the Johns Hopkins Hospital (Carr, 1909). The nurses began their training with courses that equipped them with the necessary knowledge to attend the heating and ventilation apparatus rather than the patients. The first lectures, taught by Billings's assistant, Alexander Crever Abbott, were on "Physical Properties of the Atmosphere," "Diffusion of gases as seen in the so-called "natural ventilation," "Practical methods of studying ventilation" or "Demonstration of different plans of ventilation, shown upon a model specially constructed for the purpose." Only after six weeks of instruction, once equipped with the knowledge to attend the apparatus, they were introduced to subjects like "The digestive system," "Cell life," or "Bacteria; their relations to health and disease" (Johns Hopkins Hospital, 1890a).

The most visible sign of that educational integration was the incorporation of a course on "Hygiene" into the curriculum of the Medical School. During the first year of the Hospital's operation, 1890-91, medical instructions in Pathology, Bacteriology, Medicine, Surgery, Gynecology, Hygiene, Psychiatry, and Diseases of the Nervous System were given at the Johns Hopkins Hospital. These instructions consisted of "lectures, demonstrations, laboratory courses, bed-side teaching and general clinics in the laboratories, wards, dispensary, amphitheatre, and private operating rooms." Billings was appointed as a Lecturer at the Medical School and put in charge of the department of Hygiene. The course of instructions he designed consisted of "didactic lectures" and "practical work in the hygienic laboratory." The lectures, given by Billings himself, were intended for "advanced students in hygiene and vital statistics" and took place within a month. The description of the three-months long Practical Courses covered topics such as "methods of ventilation and heating," "investigations as to healthfulness of building sites," or "the practical study of foods, clothing, habitations, etc." (Johns Hopkins Hospital, 1890b).

But critical to the functioning of the Hospital as a controlled laboratory environment was the careful and regular observation and measurement of systems of heating and ventilation. This requirement was further necessitated by the experimental nature of the heating and ventilation systems. These means of observation and study concerned both the temperature and the velocity of not just the air in the wards but also those of the hot water inside the pipes. "For purposes of experiment and observation," Billings placed thermometers in various points in the flow and return pipes of the hot water system "in order to determine the temperature of the water at various distances from the source of heat, and before and after it has passed through the heating coils and given off some of its caloric to the air passing up between the heating surfaces" (Billings, 1890).

While measuring the temperature of the water was easily achieved by using thermometers, the measurement of the velocity of hot water inside the closed and opaque pipes was more challenging. Billings's solution to measure the velocity of hot water inside the pipes was to substitute the building's hot water pipe with a "glass tube." To achieve this, he devised a special by-pass mechanism that was installed in two locations within the Hospital. The apparatus consisted of a glass tube connected to the supply pipe, both having the same diameter. A valve allowed the hot water in the pipe to be fully diverted to the glass tube where "the velocity of the stream can be measured by injecting a small quantity of colored fluid, such as solution of carmine, and noting the time required for it to pass a measured distance in the glass tube." The "two pieces of apparatus," Billings wrote, "have been inserted for the purpose of determining the velocity of the current of hot water in the pipes under various circumstances of external temperature, and thus obtaining data as to the amount of water producing a given heating effect in a given time" (Billings, 1890).

To test the effectiveness of the heating and ventilation system, Billings had his assistant Abbott record observations made in one of the wards during December 1889, a few months after the Hospital officially opened, with an average of twenty-four patients present in that ward (Billings, 1890). Abbott's observations were recorded in a memorandum, with a summary of his findings published in the *Description of the Johns Hopkins Hospital* along with a table, showing the average temperatures, the mean relative humidity, and the mean dew point of the outside air as compared with the corresponding figures for the air in the wards (Fig. 6). These quantitative methods of description reinforced the idea of the Hospital not as a finished product, an architectural or mechanical container, but as an atmospheric laboratory—a medical and an architectural one at once. The experimental hypothesis of the project laid out during the planning of the Hospital, therefore, became the underlying premise for the buildings' design, just as the buildings ultimately became a didactic demonstration of that experiment.

Figure 6

"The Average Temperatures, the Mean Relative Humidity, and the Mean Dew Point of the Outside Air as Compared with the Corresponding Figures for the Air in the Wards"

Month.	Temperature of Outside Air.			Temperature of Air in Ward.			Mean Rel. Humidity.		Mean Dew Point.		Mean Temp. in Coils.		Velocity of Incoming Air.
	Max.	Min.	Mean.	Max.	Min.	Mean.	Outs'e.	Inside.	Outs'e.	Inside.	Flow.	Ret'rn.	Average.
November	67°	27°	44.2°	75.5°	62.4°	70.4°	70.7%	33.2%	34.7°	38.5°	119.7°	110°	3 feet.
December	50.1°	33.3	43.6°	74.5°	67.3°	70.5°	73%	34.2%	34.8°	39.8°	134.8°	129.7°	3.3 feet.*

**i. e.* 1.6 feet per bed per second.

Note. Table by John Shaw Billings, *Description of the Johns Hopkins Hospital* (Baltimore: The Johns Hopkins Hospital, 1890).

John Shaw Billings's influence extended well beyond his direct contributions to the Johns Hopkins Hospital, shaping the broader landscape of academic hospitals and medical infrastructure in the United States. Billings, initially recognized for his expertise in hospital construction and hygiene through his role as the Assistant Surgeon in charge of American military hospitals, made significant strides in information management, expanding the Surgeon General's office library into what is now the National Library of Medicine (NLM) and creating a comprehensive medical indexing system (Chesney, 1943; Lydenberg, 1924). His work in sanitary reform and leadership roles in the American Public Health Association and the National Board of Health complemented his statistical and administrative prowess, as seen in his collaboration with Herman Hollerith on the development of the punch card tabulating machine (Trunesdell, 1965). Furthermore, Billings contributed to the establishment of several key institutions—including the Barnes Hospital (Soldiers' Home, Washington, D.C.), the Army Medical Library and Museum, the Laboratory of Hygiene and the William Pepper Laboratory of Clinical Medicine of the University of Pennsylvania, the New York Public Library, and the Peter Bent Brigham Hospital in Boston—reflecting the application of his architectural and medical principles that echoed the pavilion plan (National Library of Medicine, 1965). His architectural legacy, coupled with his roles as an educator, librarian, and sanitarian, illustrates a career that was integral to the advancement of medical education and practice at the turn of the century, influencing subsequent projects such as those at Brigham and Women's Hospital and the Medical College of Ohio (Garrison, 1915).

CONCLUSION

The analysis of the design, construction, and early operation of the Johns Hopkins Hospital illustrates the dynamic interplay between architecture and medicine and underscores the pivotal role this relationship has played in shaping the contours of modernity in both disciplines. This investigation reveals that the design of the modern hospital transcends simple architectural innovation, embodying instead a profound engagement with the scientific, technological, and societal transformations of the late nineteenth century. The Hopkins Hospital reveals an instance where architecture directly responds to and, in turn, influences medical practice, education, and the broader discourse on health and hygiene.

The Johns Hopkins Hospital also emerges as a testament to the era's burgeoning spirit of experimentation, where the application of scientific methods to architectural design engendered spaces uniquely tailored to the nuances of medical care, research, and education. The deliberate architectural choices—ranging from the utilization of specific materials and finishes to the strategic organization of space—were not merely aesthetic decisions but were in direct response to scientific and medical theories of the time. These choices reflect a broader narrative where architecture and the built environment serve as active agents in the institution's therapeutic and educational mandates. In doing so, the Hospital's design encapsulates a moment of disciplinary convergence, where architecture and medicine coalesce around a shared project of modernization. This convergence is not a straightforward path but a complex negotiation of professional identities, technological possibilities, and evolving understandings of health and disease. It is a testament to the Hospital's role as a crucible of modernity, where new architectural forms and medical practices were forged, tested, and refined.

In this context, the Johns Hopkins Hospital does not merely represent a historical case study but serves as a critical node in the broader trajectory of modern architecture and medicine. It illustrates how the imperatives of health and hygiene became catalysts for architectural innovation, presaging the functionalist and minimalist aesthetics that would come to define modernist movement in architecture in the twentieth century. The Hospital's legacy extends beyond its physical and institutional boundaries, contributing to a reimagined relationship between the body, space, and health that resonates within contemporary architectural and medical practices. The interaction between architecture and medicine at the Johns Hopkins Hospital, therefore, offers profound insights into the ways in which our built environments can embody and enact scientific and societal values.

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