

Perfection in the Mechanical Arts: The development of Moravian industrial technology in Bethlehem, Pennsylvania, 1741-1814

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(A paper read at the Gipson Institute, Lehigh University, on November 6, 1998)

From the Collections at Historic Bethlehem [PA]

Introduction

Some years ago, historian of technology Norman B. Wilkinson called attention to the fact that, despite the rapidly expanding state of American industry in the late 18th and early 19th centuries, the nation was still largely indebted to Europe for its technology. In an article entitled "Brandywine Borrowings From European Technology," Wilkinson referred to the estimates of French traveler Rochefoucault-Liancourt who observed, although perhaps exaggeratedly so, that as early as 1797, there were some 60 to 80 mills of varied sorts along the Brandywine River near Wilmington, Delaware. By 1804, Jedidiah Morse was able to note in his American Gazetteer that "Wilmington and its neighborhood are probably already the greatest seat of manufactures in the United States." Although by the turn of the 19th century the Brandywine river Valley may well have been the "greatest seat of manufactures," it was by no means the first or only such early concentration of industrial activity.

When the American colonial leader John Adams arrived in Bethlehem, Pennsylvania in late January, 1777, he wrote to his wife Abigail that, the Moravians "have carried the mechanical Arts to greater Perfection here than in any Place which I have seen." Although not founded until 1741, within six years the Moravians were practicing over 30 crafts and industrial trades within the community, and by the mid-1750s, the number had grown to approximately 50. Many of these heavier trades such as grist milling, tanbark crushing, oil milling, and a pumped waterworks depended on an extensive (for the period) water power system for their source of energy. It was this early concentration of industrial technology occurring along the Monocacy Creek that makes Bethlehem one of those locations that must also be considered for its nascent contribution to American technological development.

Often overlooked because of subsequent 19th century industrial activities, this early example of American proto-industrial development is, nonetheless, valuable for what it reveals about technological practice in the latter half of the eighteenth century. Why Bethlehem developed such a concentration of crafts and trades in one location at such a relatively early date, and why that growth later stagnated, helps us to understand how the economic history of the community evolved and complements much of what historians know generally about early American technological practice.

Religious and Economic Background

John Adams was just one of many colonial visitors, both famous and not-so-famous, to inspect the lifestyle of this "curious and remarkable Town" on the 18th century Pennsylvania frontier. While his description may have been among the most eloquent, there are many adjectives that can be used to describe this unique community: ritualistic, exclusive, sophisticated, cultured, self-sufficient, and industrial. Our focus on the industrial and technological elements of the community unfortunately means we cannot explain in great detail many of the characteristics that marked daily social interaction and religious life; however, some background on these latter themes is necessary to an understanding of the former.

The Moravians were a Protestant group with roots in Bohemia and Moravia in 15th century Czechoslovakia. They were followers of Jan Hus, a Roman Catholic reformer burned at the stake for heresy in 1415, who then went on to found their own church, the Unitas Fratrum, in 1457. Over the course of the next 265 years, these men and women experienced alternating periods of religious freedom and persecution, eventually ending up under the patronage of Count Nicholas von Zinzendorf, a German Lutheran nobleman. Zinzendorf invited them to live on his estate at Berthlesdorf in 1722, where the Moravians founded the settlement of Herrnhut, a town that would become the center of all their subsequent religious endeavors throughout the world. Zinzendorf played an instrumental role in defining the Moravian religious experience and thus in developing their world view regarding everything from the family and marriage to commerce, industrialism, and agriculture. Certainly for the first twenty years of Bethlehem's existence, religion was the be-all and end-all of every facet of life.

Because Moravian theology stated that salvation was open to everyone, church leaders in Herrnhut quickly began a program of mission work to spread the word of God to various cultures throughout the world. In North America, the first Moravian mission was established in Savannah, Georgia in 1735. When that settlement failed because of pressure from the English on the pacifistic Moravians to bear arms against the Spanish during the War of Jenkins Ear, the Moravians joined forces with George Whitefield. In 1740, this itinerant English evangelist had purchased 5,000 acres of land to establish the Barony of Nazareth, which today encompasses Nazareth, PA, to build a school for orphaned African-American boys. Within the course of that year, a disagreement with Whitefield led the Moravians to purchase 500 acres of their own land at the confluence of the Lehigh river and the Monocacy Creek. Here the Moravians began in earnest to establish a base for their mission activities to the Native Americans and to other German settlers who professed no church affiliation. Of these two goals, the effort to unite the Germans under one church organization ultimately failed, while the development of Indian missions proved successful, although not without problems. It is important to note here that unlike many German counterparts, the Moravians did not venture to North America in search of religious freedom. Augustus Spangenberg, the well-respected Moravian leader, wrote in 1743 that, "The purpose of our coming into this region was not to seek economic support nor to gain freedom of conscience--we did not lack either--but rather the desire to inform others also of that which we know to be conducive to the eternal salvation of mankind."

To support the efforts of the missionaries, the Moravian leadership in Herrnhut, including Count Zinzendorf, Augustus Spangenberg, and Peter Boehler, set up Bethlehem as a Settlement Congregation with two groups of workers. The first consisted of the congregation pilgrims, or missionaries, whose job was to go forth and preach the gospel and convert "souls for the Lamb." During the early years of Bethlehem, the position of missionary was highly sought after by nearly all the members of the congregation, and it was, indeed, available to the majority of the residents. This concept made for a community whose members needed to have a great deal of mobility in terms of the kind of work they did. The second group of residents were the workers, those individuals who remained in the town and, through various tasks, trades, and occupations, worked to support those in the mission field.

In contrast to most colonial communities where some 85-90% of the labor force was engaged in agriculture, in Bethlehem the figures were almost reversed, with less than 20 percent of the labor force in agriculture. This anomaly resulted from the Moravian emphasis on missionary activity as the highest calling, one in which communal members were expected to take part at certain points in their lives. The labor and seasonal intensity of farming tied men and women to the soil thereby reducing their mobility. Thus, the Moravians placed emphasis on trades that at once provided their practitioners with more mobility and the potential for more profit, and hence provided the community with the ability to place more missionaries in the field. As one Moravian noted, "the Brethren do not in the least incline toward farming." As early as 1747, some 50 members out of the community's total of 400 were performing missionary work, and in 1759, slightly more than 1/3 of the adult males were engaged as missionaries, many of whom were accompanied by their wives. Given that approximately 1/3 of the people in Bethlehem were children under the age of sixteen, on average it works out that about 1/3 of Bethlehem's total population provided the material and economic support for the community.

It was Zinzendorf's idea that Bethlehem would develop the same institutions and be governed by the same rules and regulations as Herrnhut, a notion that would eventually both make and break the success of Bethlehem in its first one hundred years. Zinzendorf had a vast array of already well-established estates, and many of the Herrnhut Moravians were of the aristocracy who drew support from the traditional feudal economy. In contrast, surviving on the colonial frontier, where everyone had to start from scratch, was a key variable that the Moravian leaders had not factored into their equation for developing the perfect way to reach salvation.

The daily activities of the Moravians were guided by a strict regime of religious norms in which the image of Christ as Head of the Church, Chief Elder, Husband, and Best Friend were vividly placed before the eyes of the believers during every waking moment, whether one was at work or at rest. This all-encompassing religious experience was of a social nature, as well. The nuclear family did not exist during the first twenty years of Bethlehem, replaced instead with a social framework called the choir system in which residents lived in groupings by age, gender, and marital status. Zinzendorf believed that the way to true salvation was through continued close contact

with one's gender peers. Large choir houses were constructed where the single men and single women could exist separately; where married couples lived in separate groups of married men and married women, not together as husband and wife; and where children were handed over to a congregational nursery when they were weaned. Such was the choir system that dominated living arrangements during Bethlehem's early years.

The Moravians instituted a form of economic communism formalized as the General Economy in 1744, which augmented the communal lifestyle. The church in Herrnhut owned all the land and buildings in Bethlehem, but they were held in trust by a trio of individuals in America--Henry Antes, David Nitschmann, and Augustus Spangenberg--because Pennsylvania law did not allow land ownership by aliens. Everyone worked for the good of the community under an agreement that was purely voluntary. The choir became a self-contained working unit in which different members performed various tasks, with the result that there was no unemployment or idleness. The system allowed for activities like the communal preparation of meals and the making and repair of clothing which spread out the cost of overhead. The choir delivered the proceeds of their labor to a central administration, and each member was assigned a share of food, clothing, and linen, and received education, health care, religious indoctrination, and old age and death benefits in return. This system was particularly useful in the early years when the majority of the population in Bethlehem consisted of single men and women. The Single Sisters took on the roles of nurses, teachers, seamstresses, laundresses, cooks, maids, gardeners, and caretakers of livestock within their own choir. The Single Brethren managed heavier industries and crafts in the community such as blacksmiths, tanners, and millers. Thus was set the economic course of Bethlehem during its early decades, and on balance life was good under the system of the General Economy.

By the 1750s, however, the world view of Bethlehem was beginning to change. In 1753, a separate branch of the General Economy dealing with trade and commerce was developed because the community's population was growing at a high rate and because neighboring individuals and communities had begun to place demands on Moravian goods and services. Self-sufficiency had always been considered a vital goal for the Bethlehem settlement. Attaining it meant that the Moravians would experience little interference from the outside world, thereby leaving their community pure. However, very early on the Moravians found that they needed to make contact with "strangers" to obtain goods that they could not make or raise such as iron, gunpowder, glass, and salt. In order to obtain the cash they needed to make these purchases, they sold their excess goods such as tanned hides and linseed oil to outsiders. The Moravians, astute business people, apparently rationalized that if neighboring settlers could purchase the items they needed locally, why should Bethlehem lose their business by forcing them to travel the distance to Philadelphia for the same products. Thus, with the establishment of the Strangers Store in 1753, Bethlehem became a center of commerce in which Moravians and non-Moravians were forced to interact. The community erected the Crown Inn (1745) and the Sun Inn (1758) as controlled lodging places for non-Moravian visiting tradesmen and others who needed to access services and goods at Bethlehem. Church leaders justified the promulgation of such endeavors by requiring that the profits

be turned over to the central administration and distributed to all of the residents. A trades conference fixed all the prices charged, and outsiders who came to Bethlehem were not allowed to bargain.

By 1761, the land owned by the Moravians in Bethlehem, Nazareth, and the surrounding countryside of the so-called "Upper Places" was valued at over \$12,000 in Pennsylvania currency. Their buildings were valued at slightly more than \$22,200, while the goods on hand from trades, commerce, and agriculture amounted to about \$10,000. The total assets of the General Economy came to almost \$50,500. However, with the increase in the standard of living enjoyed by the residents and the general prosperity shared throughout the community also came church debt, which amounted to a little more than \$20,000 of which three-quarters was borrowed capital, with much of the remaining incurred as expenditures for food and clothing not producible by the General Economy, as well as for the community support of the young, old, and the ill. While the net balance of assets over liabilities was about \$30,000, it was tied up in land and not available as ready cash. At the same time, the missionary effort, which was still prominent, absorbed cash that otherwise might have been utilized for debt reduction or further economic ventures.

Thus, by the late 1750s-early 1760s, a new spirit pervaded Bethlehem, a spirit that would eventually lead to a change in the economic system. Wealth and prosperity, in part the result of interaction with the outside world, increased the desire of many craftsmen to create independent businesses of their own. Tradesmen and craftsmen, tired of the economic constraints placed on them by the church, were still willing to support the church, but by working for a profit.

At the same time, the missionary system also began to change. Whereas in the early years of Bethlehem everyone could aspire to be a missionary, as the community grew and prospered, tradesmen and craftsmen occupied a more prominent economic position because the burden of generating revenue rested squarely on their shoulders. They gradually lost the mobility they had enjoyed in the early years to leave their professions, become missionaries, and in time return to the community and pick up where they had left off economically. A class of professional missionaries had developed, and many workers resented supporting people who had attained a station in life to which they could no longer aspire.

The choir system gradually became less popular as well, for workers wanted to regroup as nuclear families and provide for their own children and spouses. Indeed, the choir system had failed to sustain the religious fervor of the original settlers in raising the first generation of children totally committed to its care.

The final element in the breakup of the General Economy, however, was Herrnhut's insistence on closer supervision and control of all affairs in Bethlehem. Herrnhut, after Zinzendorf's death in 1760, found itself in extreme debt and now looked upon its religious "child" on the other side of the Atlantic, with its successful trades, crafts, and industries, as a source of revenue rather than as a missionary center that absorbed

money. Bethlehem's leaders sought to meet these challenges by opting to operate on their own and to develop plans to transform the community from communism to capitalism.

Thus, in 1762, the General Economy, which had been established to cope with the special conditions of frontier America, was abolished. The church retained ownership of all the land and buildings and would continue to do so until 1845, but great changes began to occur in the way the community conducted its everyday life. Some of the original ventures at first became more socialistic in nature, with agriculture, the mills, and the strangers' store remaining under community control for the next few years. The church now paid people working in these socialized branches a small wage to continue their efforts. The church also continued to fund the education of resident Moravian children and the social welfare of the destitute. In the areas of trades and crafts, individual masters now began to take over their own businesses. They could purchase the capital assets needed to ply their trades, which included the workshop or house (but not the land), the fixtures and tools. Residents of the choir houses began to pay for their room and board. The church reorganized missionary work and financed it primarily from Herrnhut, no longer from Bethlehem. People began to live in nuclear families and to pay for most of their social services. The church also began to consider in earnest where these nuclear families would reside and instituted an expensive building program to construct single family homes and to renovate the choir houses into multi-family apartments.

The attempt at socialization eventually failed, however, because the church continued to incur more debt to support the remaining workers on its payroll. In 1766-1767, the farms were handed over to tenant farmers, with only the store, the inns, and the major mills remaining under control of the church. Finally in 1769, all remaining communal ownership of economic enterprise was abolished.

The changes wrought, however, did not mean that individual tradesmen were no longer under the control of the church, for in 1771, rules were adopted that served to restrict the economic freedom of the individual. The church had to give its consent to the establishment of a new industry, the expansion of an existing one, or the development of a subsidiary industry. Similarly, it had to consent to the hiring and firing of apprentices. The church also had to approve the borrowing or lending of money. No businessman could develop a trade monopoly. A person could own his house, but not the land on which it stood, for the land still belonged to the church. The sale of a building on that land had to be approved by the church at a church-approved price. Bethlehem continued to remain exclusive until 1845 when the lease system was finally terminated and both resident Moravians and non-Moravians, who were first allowed to live in Bethlehem in 1810, could purchase property. Such was the state of the community when John Adams visited in 1777 and penned his impressions of this "curious and remarkable Town."

Crafts and Trades

Among the vivid impressions recorded by Adam was his sense of the "remarkable" "Industry and Economy" within the Bethlehem community and the "fine sett of Mills" laid out along the Monocacy Creek. Almost from the beginning, the spectrum of trades practiced in Bethlehem was quite broad. Thomas Pownall, who would later become Governor of Massachusetts but in 1754 was serving in a semi-official capacity as an observer for the Board of Trade, provided a revealing catalog of trades.

There were, when I was there, the Following Trades carried on by the Fratres at this Settlement. Saddle-tree maker, Sadler, Glover, Shoemaker, Stocking-weavers ..., Button maker, Taylor & Women Taylor, Hatter, Ribband-weavers; Linnen-weavers ..., Woollen-weavers ..., Wool-comber, Dyer, Fuller, Dresser, Tanner, Currier, Skinner, Butcher, Miller, Chandler, Oil-maker; Baker, Cooper, Joiner, Carpenter, Mason, Glazier, Brick maker, Stone Cutter, Turner, Potter, Stovemaker, Wheelwright, Blacksmith, Gunsmith, Nailmaker, Lock-smith, Pewterer, Tinman, Silver-smith, Clockmaker, Harries-maker, Hemp dresser, Boat-builder, Surgeon, Apothecary.

Clearly we cannot talk about forty odd trades in this essay but we can identify and focus on several of the more important industries. Thus, we will discuss those industries that were both central to the economic well-being of the community and which, because of their locational concentration and heavy dependence on water power, gave Bethlehem, if not a unique history, certainly a special place in the history of early American technological development. The American colonial age has been sometimes characterized as an age of wood and water, for most things were made of wood, although iron was clearly well-known and used. Beyond the animate sources of power found in humans and animals, waterpower was the major energy source for operating early manufacturing processes such as saw and grain milling, two of the more important industries found in most colonial communities of even modest size. In Bethlehem, most of the lighter crafts, such as spinning and linen weaving by the Single Sisters and tailoring and cobbling by the Single Brethren, were performed in the "upper" residential portion of the town. The heavier crafts such as those found in the pottery and blacksmith complex, or those that required waterpower, were concentrated along the Monocacy Creek or nearby and were also operated by the Single Brethren. It is this latter industrial quarter on which we have chosen to focus our attention. In particular, we will examine Moravian efforts at grist milling, oil milling, and tanning, the last two industries being particularly important as sources of outside income. Finally, we will look at the waterworks, the first pumped municipal system in the American colonies. Each of these trades and industries played an important role in the development of Bethlehem's religiously-based economy; collectively they reveal an interesting picture of early American technological development.

Grist Milling

The year 1743 witnessed the construction of several of early Bethlehem's most important mills and craft shops, among the very first of which was the gristmill. Grist

milling--the grinding of grains into flour--was viewed as so important to a community's well-being that towns often offered inducements such as free mill sites and adjoining land, limited monopoly rights, exemptions from taxes and military duty, and even outright monetary gifts to millers to settle and establish there, for mills were seen as contributing to increased land values and as mechanisms to attract settlers to a new town. Lack of a mill was perceived as "a serious evil" and, as one Vermonter put it, "inconsistent with civilized life." Grist mills were often erected before churches and schools. Prior to the construction of their own mill, Moravians ground their grain into flour at a mill owned by Nathaniel Irish and located on Saucon Creek near the present-day town of Shimersville. While Bethlehem did not have to offer the same inducements to establish a mill as many other communities, the fact that it was the first mill building to be erected testifies to its importance within the new settlement.

Bethlehem's first grist mill was a log structure erected on a stone foundation. It was built by Gotthard Demuth, a Germantown, PA man, with machinery designed by Henry Antes, a miller and millwright from Frederick Township, Montgomery County. Antes helped the Brethren establish themselves at Bethlehem. He subsequently became a trustee of the Unity and has been regarded as Bethlehem's early town planner. Quickly outgrowing the capacity of this first mill, the Moravians erected a second mill on the same site in 1751. The new two-story structure was built of limestone quarried locally from Nisky Hill. Within two years the community added a second run, or set, of millstones to accommodate the many settlers from the north and west of Bethlehem who brought their grain to this location for grinding.

The new grist mill also included a woolen fulling operation located on the west side of the building to complement the work of four weavers who had arrived several years earlier and begun manufacturing cloth. Fulling involved the cleaning and shrinking of the newly-woven cloth, first by washing and then stamping or beating it using fuller's earth, an absorbent clay which removed excess oils from the wool. It was then washed again to remove the clay, dried, and "napped" or trimmed to even out the fibers before being transferred to the dyer. In 1759, an addition was built onto the west end of the grist mill to house the fulling mill, a dye house, and the cloth weaver's shop. This new fulling mill, which operated until 1820, was "capable of running through three hundred yards of stuff at once."

Probably two breast wheels powered Bethlehem's early grist-fulling mill complex. They utilized water from a small pond created by a low dam located a short distance upstream for the source of power. The master miller controlled the flow of water to his wheel through a sluice and head race. Although less efficient than an overshot wheel might have been, the relatively shallow drop in water height of the Monocacy dictated the use of either a low breast wheel or an undershot wheel as was utilized downstream in the waterworks and oil mill. The grist mill's tailrace returned the spent water to the Monocacy at a point just above a second dam. Taken together these dams, raceways, and waterwheel collectively formed a water power system, which, even if not unique in its concentration and complexity, certainly pointed to the holistic techno-economic planning of the Moravian community.

The Moravian Congregation controlled and operated the grist mill through a series of millers who initially lived in the mill building itself. In 1782, master miller Hermann Loesch complained that the space devoted to his living quarters might better be utilized for grain storage and petitioned the Church for separate quarters. Two years later, the Overseer's Conference subsequently acceded to Loesch's request and authorized construction of a separate stone miller's house adjacent to the mill. It consisted of a large living room area, kitchen, and cellar. This building was enlarged in 1834 with a one-and-one-half story addition, both parts of which still stand today. The Church continued to operate the grist mill until 1825 when they leased it to George Henry Woehler. Five years later the Church sold the mill to Charles A. Luckenbach who began to modernize the operation. Unfortunately a devastating fire destroyed the building in 1869. The Luckenbach family promptly erected in its stead a new four-story brick building on the remaining stone foundation, which is the building restored today. This third grist mill on the site remained in operation as a feed and flour mill under various owners until the early 1950s. Although little else is known regarding the specific details of the construction and operation of the two 18th century grist mills, we can be sure that they played a central role in the still heavily agriculture-dependent community.

Oil Mill Complex

In Bethlehem, as in many 18th century communities, linen was a more common fabric than wool, and certainly more so than cotton, which was harder to grow and process during this time period. Flax, from which linen is derived, contains seeds, some 30-40% of which is linseed oil. However, because the oil can be extracted only under fairly high pressure, requiring capital-intensive equipment investments, it was unusual for individuals to attempt to process it at home. Rather, it tended to be a concentrated industrial process. Linseed oil was commonly used in paints, printers' ink, and in certain medicines. Given the Moravians' planned economy, predilection for mill building, and need for cash crops and products, it must have been deemed logical to enter the business of pressing linseed oil for their own and others' use. Thus, as early as February, 1745, the Bethlehem Diary records that, "The oil mill was complete enough for our Brethren to make the first linseed oil."

The first oil mill was a small, log structure located on the east side of the tailrace of the grist mill. Although the documentation is scanty, the mill's location and the one extant drawing suggest that this was unlikely to have been a waterpowered mill, but rather a "press," perhaps powered by a horse. In any event, this first mill was shortly replaced in 1752 by a larger frame structure that housed hemp and bark milling machinery, as well as that for oil processing. This new mill was designed and built by Hans Christoph Christensen, a 35-year-old Moravian millwright-carpenter from Herrnhut who had emigrated to Bethlehem in 1751.

Christensen, a Dane by birth, had worked in a royal grist mill for several years before joining the Moravian Brethren for whom he worked as a carpenter in several towns including Neusaltz in present-day Poland and Herrnhut before receiving the call to travel to Pennsylvania. Once there, his first assignment was the building of an extension to a

grist mill in the Moravian community of Friedensthal. While Christensen's millwrighting skills may have still been evolving at this early date, he soon proved himself a master builder and was centrally involved in the construction of a number of mills, not only in Bethlehem, but also in other Moravian communities and for private owners as well. Christensen presumably deepened his knowledge of millwrighting as he traveled and worked throughout Pennsylvania and other colonies, but just as surely he transferred technical skills and approaches to his work derived from European, especially Danish and German, practice.

Few records or images of the 1752 oil mill exist today, however, those that do survive indicate that, unlike the 1745 press, this was a combination mill housing oilseed stampers and a press, as well as both tanbark and hemp stampers. In fact, the mill was frequently referred to as the "stamping mill." It was powered by a single undershot waterwheel that drew on water restrained by a new dam erected just above the mill. The new mill was operated initially by George Christ and after 1757 by Albrecht Klotz. Following the 1762 abrogation of the General Economy, John George Geitner, the tanner, became responsible for its operation. The new mill produced some 750-1550 gallons of linseed oil annually for the Moravians alone, a figure that does not count extensive sales outside the community. This was a production level four or five times that of the 1745 mill and served the economic vitality of the community well. Unfortunately, on November 18, 1763, a fire broke out at night, probably the result of white arsonists angry over the Moravians' pacifistic stance during Pontiac's War, resulting in "substantial" loss according to the Bethlehem Diarist. With the mill, in effect completely destroyed, excepting the waterwheel and some iron work, the Brethren quickly began planning to rebuild.

John Arbo, the warden, or financial manager, of the Single Brethren's Choir under the recently reorganized economic system, oversaw construction of the new mill. Christensen served as the millwright for the project, which was designed to incorporate not only the linseed oil, hemp, and tanbark processes from the previous mill, but also additional machinery for grinding cereal groats and for fulling leather, as well. The multiplicity of operations proposed for the new mill clearly made it more than an "oil" mill and spoke to the synergy among Moravian industries but also raised questions and tensions over how best to operate the new mill. Church administrators had determined that the Single Brethren should build and manage the new mill. The last supervisor of the previous mill had been Johann Geitner, the master tanner, who was not a member of the single Brethren's Choir. Even though the design of the new mill called for two waterwheels to run all the additional machinery, it was clear that reduced water levels due to extended drought and the recent (1762) construction of a new waterworks (to be discussed below) meant that not all the equipment could be operated at once. Geitner, concerned for the efficient functioning of the tannery, argued that even if he was not allowed to operate the tanbark stamping and leather fulling components of the mill, he should have ready access to the fulling mill whenever he needed it for processing hides removed from his tanning vats. In the end, it was agreed that the tannery should pay an annual fee of \$25 for running the tanbark stamping operation, while leather fulling never

became fully operational there, apparently being conducted in the cloth fulling mill instead.

With the end of hostilities associated with Pontiac's War, Christensen was able to draw up a plan for the new oil mill at the end of 1764. During that winter the Moravians quarried and stockpiled limestone and prepared the timber for the new building, and in July they laid the cornerstone. By the end of September, the walls of the 33' x 66' mill were two stories high, and the new dam for powering the double waterwheel was almost complete. Bethlehem's Diarist noted, "This will be one of the most solid and durable buildings and the only one of its kind to be found in this land." At the same time the building itself was being erected, the Brethren were also installing the twin undershot waterwheels, each of which was 17.5' in diameter and 4.5' wide and capable of developing about five horsepower. The east wheel operated the linseed stampers and oil cake crushers and drove the millstones for the groat mill on the second floor, while the west wheel operated the tanbark stampers, the hemp mill, and later a snuff mill. On December 27, the hemp mill began operation, with the oil milling machinery becoming operational in mid-February 1766 and the tanbark mill starting in early March. The hemp roller mill was installed in late 1767, but the specialized snuff mill not until 1794. Thus, right from the beginning this was designed as a sophisticated combination mill, in contrast to most mills of the colonial era that started out as single purpose mills and only later added secondary tasks. Christensen rightfully considered the oil mill his greatest engineering achievement.

The oil mill became one of Bethlehem's most profitable businesses during the next 20 years, based primarily on the sale of linseed oil, barley groats, and oat meal. A decline in profitability, including a number of years of losses, followed the end of the Revolutionary War, perhaps a result of the general post-war economic downturn. After the turn of the century, modest profitability returned, but other expenses, associated with the Single Brethren's Choir, led the Church in 1814 to disband this group and lease out its industries to private tenants. At this point the use of the building changed also, with the focus shifting from oil milling to grist milling utilizing the groat mill equipment. Finally, in 1832, the town relocated the waterworks into the oil mill building, utilizing the east waterwheel, as the earlier 1762 pumping system had become inadequate to the task.

Returning to the 18th century, there are at least two important points that can be made about the oil mill complex that are revealing about the Moravians' economic planning and technological development. The first, alluded to previously, was the synergistic relationship between the industries contained in the building, as well as their relationship to other needs outside, in particular the tanning industry. Given the relatively small size of each of the industries, it would have been too costly to erect separate mill buildings for each. This restriction was combined with the limitation imposed by a relatively small, two-foot head of water behind the low dam, which could provide little more than a day's supply of water if used constantly, especially as the same dam also supplied the waterworks. As a result, it was not uncommon at times of low water for the oil mill to be idled in order to pump water for the growing town's

domestic needs. Similarly, the tannery depended on the mill for a ready supply of tanbark at the rate of one or two times the weight of each hide. Since the tannery processed several thousand hides annually, this entailed extensive amounts of tanbark. Tanners like Geitner periodically complained about the lack of necessary amounts of tanbark, often due to the limited amount of water available to power the mill. Finally, in the early 19th century, tanbark stamping at the mill ceased in favor of a separate horse-driven bark mill, again suggesting the required coordination of the various industrial trades pursued by the Moravians. Thus, it seems quite evident that an operationally flexible system that could be regulated depending on product/process demand and seasonal water availability was required. That Arbo and Christensen recognized this need and were able to achieve it is testimony both to their organizational and technological skills.

The second point that should be emphasized is that technological processes contained within the mill drew heavily on central European and especially Germanic traditions. As they had in their central European homeland, Moravians used hemp as a key fiber in the production of clothing. John Arbo's 1766 advertisement in the Pennsylvania Gazette announcing the opening of the new mill for business noted that "The Hemp is not rubbed with a Pumicestone in the common Way, that being attended with many Dangers; but it is stamped in a particular Manner, and becomes pliable and fitter than with the Stone." This use of stamps for softening, which can be seen in other Germanic drawings, suggests the transfer of that technological process to Bethlehem, as does the 1767-68 installation of a German-style hemp mill utilizing a stone roller, called in German a Hanfreibe or "hemp rubber," to soften the fibers. Whether or not the latter installation implied the inadequacy of the stamper or not, it nonetheless points to the American adoption of European technological traditions during this period. So too does the Moravian adoption of tanbark stampers utilizing large 18' stampers with iron heads incorporating cutting knives on the bottom, which resulted in a coarse tanbark powder. In contrast, the more common American bark mills were horse-driven affairs utilizing a cylindrical stone which rolled on a circular bed, thereby crushing the bark. In both cases then (and similar arguments about the technology utilized in the groat and snuff mills can also be made), Moravians clearly drew on European-Germanic practices in designing the technological hardware for the oil mill complex. In many ways this should not come as a surprise, and it is the key argument set forth by Norman Wilkinson in his analysis of Brandywine river industries in the early 19th century.

Tanning

The other major industry located along the Monocacy that needs to be discussed because of its importance to the Moravian economy was the tannery. Bethlehem's overseer, Bishop John Cammerhof, reported in the 1740s that the tannery "is one of our most paying [ie., profitable] and indispensable trades. It supplies all our shoemaking trades, all our people with leather, and for horse harnesses and other things in the housekeeping." Bethlehem's industrial quarter was an ideal location for a tannery for several related reasons. First, it had a ready source of water in the Monocacy for the washing of hides and for activating the tannin in the tanbark. Second, the fact that the

Moravians ran one of the largest cattle raising operations in the colony meant that there was an ample supply of hides. Third, extensive forest lands to the north of Bethlehem supplied the large amounts of bark, mostly oak, which the Moravian tanners needed for the tannic acid utilized in the soaking stage. Usually peeled in the spring when the tannin concentration was at its peak, there were frequently over 100 cords of tanbark on hand at any point in time.

Tanning, as J. Leander Bishop, the 19th century historian of American industry, noted, seldom lagged "long behind the first occupants of a new town." Bethlehem, which erected its first wooden framed tannery in 1743, was no exception. The craft knowledge that underlay the tanning process was generally well understood in the mid-18th century and traveled to the colonies firsthand in the heads of tanners or in a number of books fairly readily available at the time. The tanning process was lengthy—taking up to two and one-half years—and laborious with little but the crushing of the tanbark, as already noted, being mechanized in any way.

As with many of the industries along the Monocacy, the Moravians utilized two buildings for tanning during the course of the period under study. The first tannery was a small log structure built in 1743 on the east side of the grist mill tail race. This building may, in fact, have also been a tawery in which skins were treated with mineral substances such as alum and egg yoke or fish oil to produce finer quality leathers for gloves, bookbindings, and the like. This process was also frequently referred to as white tanning, the name deriving from the lighter colored, or white leather that resulted from the process. Tawing or "white tanning" usually utilized the softer and thinner sheep and deer skins, as opposed to the thicker cow hides used in the bark, or as it was sometimes called "red," tanning process. Moravian white tanners worked mostly with the more plentiful deerskins, sheep being needed for their wool, and apparently used a fish oil tanning medium to produce what was called "chamois" leather.

As the community and tanning operation grew, the Brethren saw the need for a larger, more permanent, structure. In 1757, the community leaders approached the master tanner Johann Georg Geitner and asked him to design a new limestone building. Erected in 1761 on the west side of the grist mill tail race, the tannery measured 30' x 66' and was four stories tall. The records are scanty as to the specific uses of the tannery's rooms; however, it is clear that the vats were located on the ground floor, while the third floor was utilized for drying. It is also probable that the master tanner and his family lived in rooms within the building. Other rooms were available for "preparing things" and may have housed the currier's operation as well. The tannery remained in the hands of the Moravian Congregation until 1829 when it was sold to Joseph Leibert and his son James, who would be the first of a series of private owners to operate the business until it finally ceased operation in 1873 due to the high cost of tanbark.

Although the tanning operations, with the exception of the tanbark preparation and the leather fulling, were not as mechanized as the grist and oil mills or the waterworks, this industry also played a vital and synergistic role within the Moravian economy. The tannery at once supplied Bethlehem with the leather needed for the Brethrens' shoes,

saddles, and harness tack, clothing, and even for specialty luxury applications such as bookbinding. At the same time, the tannery made use of hides from animals slaughtered in large measure for food, which would otherwise have gone to waste. In addition, the tannery processed hides from Moravian mission stations in Jamaica and the West Indies, as well as from nearby non-Moravian settlers, thereby enhancing the cash flow of the community. As with many of the other crafts and industries, tanning had to be closely coordinated with processes conducted under the roofs of other mills, most notably in the production of tanbark and at the fulling stage. Even though tanning was a noxious industry, and one that significantly polluted the nearby Monocacy Creek, the Moravians recognized the economic centrality of the trade and continued to operate its tanneries until well into the 19th century.

Waterworks

One final process conducted within the industrial quarter along the flood plain of the Monocacy that deserves mention was not that of a production industry per se, but one that nonetheless provided an essential service to the community--the waterworks. When John Adams visited Bethlehem in 1777, it was this example of what he called "the mechanical Arts" that he described most extensively. Bethlehem's waterworks was the first pumped municipal system in the American colonies and replaced the use of horse and wagon for the distribution of water from the clear spring located at the base of the hill to the residential area located some several hundred feet away on the crest of the hill, where the water was used for domestic purposes and in case of fire. The "sett of pumps" that Adams witnessed in operation, however, was not the first such endeavor, for as with most of the Moravian industries and trades, it had passed through an earlier stage.

Following several earlier unsuccessful attempts to pump water, Hans Christensen, the Danish millwright who had arrived in 1751 and helped design and construct the first oil mill, turned his attention in early 1754 to the water supply problem. Christensen worked closely with carpenter John Bohner, who had built a model of a pump, to design the mechanics of a water supply system. They tested the pump in June by connecting it to the waterwheel of the 1752 oil mill, successfully pumping water some 90 vertical feet to the residential area. Although Christensen left Bethlehem to travel to North Carolina to engage in the building of another mill, the Brethren completed the waterworks in his absence. This first pump house was a 14' x 18' frame building situated some 300' south of Bethlehem's main spring to which it was connected initially by an open trench raceway and after 1765, by hollowed-out hemlock logs that served as piping. Inside the pump house was a pump, probably with two cylinders, constructed of *lignum vitae*, a tropical hardwood, probably brought from the West Indies where the Moravians maintained missions in which Bohner had served. Utilizing a walking beam, or locker, type of pump, the system was able to pump water to the collection tower, which was located on the site of the present-day Central Moravian Church, a vertical height of 95' at a distance of somewhat over 300'. From the holding tower, the water flowed by gravity through a series of wooden distribution pipes and cisterns to the major residential and commercial buildings. Despite its initial success, this first system soon

encountered problems, including wooden pipes that burst under pressures in excess of 40 psi, the design of the pump itself, and the location of the waterwheel within the wheel pit, all of which contributed to an insufficient supply of water for a rapidly growing town.

As early as 1761, Christensen, John Arbo, the overseer of the Single Brethren's Choir; and Frederick von Marschall, the overseer for the community's economic and financial matters, were laying plans for a new waterworks to replace the inadequate 1754 system. Working closely with Christensen was an assistant, Christopher Demuth; together they had substantially completed the pumping machinery by 1762. However, the surrounding building was not completed until 1764. When finished, the 24' x 30' limestone building stood two stories high with a red tile roof. Inside the waterworks was machinery described by Christensen's apprentice, John David Bischoff, as consisting of 3 single-acting force pumps... of 4 inch calibre and 18 inch stoke, worked by a triple crank... geared to the shaft of an undershot wheel. 18 feet in diameter and 2 feet clear in the buckets.

The head of water was 2 feet. On the water wheel shaft was a wallower of 33 rounds, which geared into a wheel of 52 cogs, attached to the crank; the three piston ends were attached each to a frame or crosshead working in grooves to give them a motion parallel to the pumps. The crossheads were of wood, as also the parts containing the grooves for guides.

What is perhaps most revealing about the state of Moravian technology in this quotation, a point further confirmed by a set of 1766 machinery drawings for the waterworks regards the use of crossheads operating in grooves. By utilizing a connecting rod attached between the oscillating motion of the crankshaft and the top of the crosshead, which was restricted to a vertical motion by the grooves within which it ran up and down, the pump piston was prevented from rocking side to side and thereby wearing the cylinder. For the time period under discussion, tills were a very advanced technological solution to a problem that had long confronted earlier technicians, suggesting that the system was no mere jerry-rigged frontier solution, but rather the application of state-of-the-art knowledge, presumably transferred from Europe.

Another example that further illustrates the important transfer of technological knowledge from Europe to Bethlehem can be made with regard to the design of the wheel itself within the waterworks. The undershot wheel, which was 18' in diameter, utilized a two-foot head of water flowing at about 400 gallons per minute to develop about 3.5 horsepower by turning at a maximum of 7.5 revolutions per minute. In contrast to almost all American-designed waterwheels, such as those described later in 1795 by Oliver Evans in *The Young Mill-Wright & Miller's Guide*, which were of a "compass-arm" design, the Bethlehem waterworks utilized a "clasp arm" design. Whereas the compass-arm design entailed mortising or pegging the arms of the waterwheel to the central shaft, the clasp-arm design wedged them to the outside of a square shaft. The significance of this distinction is that the latter was typical of 18th century Danish waterwheel, a design more than likely utilized by Christensen as a result of his early experience in the royal Danish grist mill in Haderslev where he worked prior

to emigrating first to Neusalz and then to Bethlehem. Here the point to be made is not whether one design was better than the other, but rather to point once again to an example of the ways in which European-derived technological knowledge was transferred to America, in this case presumably in the mind of the millwright Chistensen.

While the pumping mechanism and the waterwheel were central elements in the waterworks, so too were the raceway and the distribution piping, for this was a technological system in which all the components needed to function interactively. Failure of any one part meant the system as a whole failed. Bursting pipes, whether due to freezing weather or their inability to sustain the pressures involved, were perhaps the most significant early problem. Early experiments with rolled sheet lead, terra-cotta, and wooden pipes all proved problematic. In 1786, it was "decided to lay lead pipe, for the present from the waterworks to the water tower, to test their worth" Apparently the experiment was successful, for subsequently all the main pipes were replaced by lead. Even though the Moravians understood the health dangers of lead, cast iron pipes would not be first introduced until 1813 due to their cost. The wooden distribution pipes between the water tower and the various buildings were not subject to the same pressures, although they could freeze, and so suffered fewer problems than the main line.

At the same time that the Moravians experienced problems with their piping, they also had to battle fluctuating water levels and increased competition for the limited flow of power available from the Monocacy. In part the problem resulted from apparent silting behind the grist mill dam, which affected the flow of the creek, and in part as a result several millers, each of whom competed for power, both between and within mills. This was especially problematic for the waterworks, which drew on water retained by the same low dam as the oil mill. The situation was so bad that, in 1791, the Overseer's Conference ordered the sluice gate of the waterworks stand open at all times in order that there be a sufficient supply of water for the wheel. In 1799 the wheel itself was adjusted within the pit to take the best advantage of the now lower water levels, and finally in 1810 the wheel pit and the head race were rebuilt to take advantage of the "smallest amount of water," and so that the water entered the pit at less of a sharp angle, thereby increasing the velocity with which the water hit the wheel's paddles. Apparently these changes were successful, for after this modification, there were no further complaints about water supply. Christensen's machinery continued to operate well until 1832 when the waterworks was shifted to the oil mill next door where a new pump had been installed.

Overall, the 1762 Bethlehem waterworks was a successful community endeavor, serving its citizens well for seven decades. It incorporated in its construction the best of European technological understanding coupled with pragmatic on-the-spot adjustments as components subsequently revealed flaws or the system required balancing, such as occurred due to fluctuating water levels. Bethlehem's waterworks was designed as a technological system within the larger socio-economic system that was Moravian Bethlehem. Thus, it was as much a societal endeavor as it was a fascinating technological achievement. Brooke Hindle, in his dedicatory address upon the occasion

of the 1976 reconstruction of the waterworks, attributed its distinctiveness to two differences between Bethlehem and other American communities. The first, which was technological, resulted from differences between England, which had far fewer waterpower sites and had long since denuded its forests, and therefore turned very early to steam power, and between northern and eastern Europe, the homelands of the Moravians, and especially of Christensen, which were more greatly endowed with water power sites and a technological tradition associated with them. Secondly, he suggested the communal tradition of the Moravians, in contrast to the individualism more typical of English settlers, might go a long way toward explaining the successful development of this early community water system, in contrast to other American towns. Although perhaps simplistic in some ways, by extension, it is this same combination of technological borrowing and community planning that explains the location, design, and early successes of the entire complex of mills along the Monocacy.

Conclusion

The Bethlehem that John Adams described in 1777 was, indeed, a remarkable and curious town; however, its economy reached a high-water mark during the last third of the 18th century. Had Adams returned at the turn of the century, he would have found little changed from his earlier visit. Given the seeming promise of the "mechanical Arts" in Bethlehem's early industrial development, one must ask why the community had not become one of, if not "the greatest seat of manufacturers in the United States," rather than seeing that accolade attributed to the Brandywine River mills near Wilmington . The reasons were varied, with some resulting from forces external to the community, while others emanated from within. Collectively, however, they took their toll on the growth of the town, leading to a distinct period of stagnation at the end of the century.

During the colonial period, Bethlehem's economic growth must be viewed within the context of British mercantile laws. These laws reflected the British view of the colonies as suppliers of raw materials that could be shipped to England for conversion into finished goods, which could, in turn, be exported to the colonies for purchase. Such laws, of course, were designed to protect the British home industries from competition, and cloth manufacture was one of the industries so protected. Many communities chafed under such restrictions, and Bethlehem was no exception. As early as 1752, the Moravians ran into difficulty because British administrators complained to community leaders that the volume of wool and linen cloth produced in Bethlehem surpassed the amounts allowable under mercantile law. Generally what was allowable was the amount of cloth needed to accommodate basic family needs. Thus it was that Spangenberg wrote to Zinzendorf regarding his fear that, "it might ... cause apprehension partly to the local merchants, partly to the House of Commons in Old England, if they would get the wrong news about it, ... that could not be reconciled with the laws of England in general and with our Pennsylvania law in special." He went to great pains to insure Zinzendorf, and Parliament, regarding the "lawfulness" of the Bethlehem "cloth Factory" and promised "to evade any trouble as well as is possible." While other colonial artisans at

first labored under, then complained, and later agitated to have these laws revoked, it is understandable that the pacifistic Moravians did not want to go against the wishes of the royal government, which had granted them special dispensations regarding the taking of oaths and performing military service and legally recognized them as an "Ancient Protestant Episcopal Church" in England and its colonies, thus giving them the same status as the Quakers.

A second more direct influence on the growth of the community was the economic restructuring imposed by the Church following the breakup of the General Economy. The church continued to maintain strict control over the economy and the community, which remained closed to non-Moravians. For example, church approval was still required to start new businesses and for the hiring and firing of apprentices. The new rules, although more socialistic than the earlier communistic order, nonetheless, proved too restrictive for many young Moravians no longer imbued with the earlier missionary zeal. As a result, the choir system began to decline. Men and women who found the restrictions too limiting left the community and, as a result, the population of Bethlehem began to stagnate. At the height of the General Economy, 1,300 people had resided here, but from 1765 to 1800, the average yearly population of Bethlehem was only about 600. As young men, many of whom lived in the Single Brethren's Choir which retained responsibility for many of the heavier industries including operation of the oil mill, moved away, they took with them skills required to run the crafts and trades so prominent in early Bethlehem. As a result, many of these industries began to lose money. The Single Brethren's Choir, which had numbered 100 members in 1783, could count but 38 in 1806. These men had also become a behavioral problem, sometimes disturbing services held across the street in the newly-constructed Central Moravian Church. In 1814, the choir was formally disbanded, the various trades under its control, including operation of the oil mill, were leased out to tenant operatives, and its choir building was turned over to the Moravian Seminary for Young Ladies.

A third technological type of limitation included two elements. As noted above, there was but a minimal amount of water available from the Monocacy Creek. Although not all of Bethlehem's crafts required water for power, many of the more significant ones did, and with flows restricted as they were, the opportunity for dramatic expansion was limited. When this limitation was combined with the fact that during the General Economy the Church was in effect using profits from the trades to finance missionaries in the field rather than making capital investments in new mills, equipment, or other possible ventures, it meant there was little likelihood of economic expansion or technological development, despite the earlier transfer of innovative European technical knowledge. It should be pointed out that the Church apparently felt no overwhelming need for industrial expansion during this period, its immediate needs largely being satisfied by the existing economic and industrial arrangements. This is in contrast to some other areas, such as the Brandywine River Valley at the turn of the 19th century, where capital investment was sought after to underwrite industrial growth.

A final constraint, surely of equal importance, although harder to document concretely, pertained to the density of artisans and tradesmen within the community. For all but the

most densely inhabited colonial cities, industrial development had been a very slow process. For most communities the number of craftsmen per capita was too low to encourage the technological exchange that occurs when many similarly skilled people work closely together and collaborate to invent or improve upon products and processes. Coupled with the ready availability of land in colonial America to nearly everyone, this meant that the special class of workers needed to run industries was generally slow to develop. In Moravian Bethlehem, with its early concentration of water-powered mills and where the balance between farmers and artisans was almost reversed from the colonial norm, with less than 20 percent of the labor force engaged in agriculture, one might have anticipated precisely the kind of concentrated artisanal skills that would have led the community to become a "great seat of manufactures." Almost paradoxically this was not to occur. In large part, this was due to Moravian church policy which forbade more than one craftsman in most given trades. This meant that despite the number of different mills and trades, and the synergistic interactions that took place among them, there was still not the concentration of artisanal skills needed for industrialization to really take off. Even though the town continued to grow in some ways--for example, the building of new nuclear family housing, the construction of a Girls Seminary building (1790) the spanning of the Lehigh river with the first bridge (1794), and the erection of Central Moravian Church (1803-1806)-- which testified to the town's belief that it would eventually weather the economic downturn, the Moravians' hopes would not be fulfilled. The church's ongoing rigid control of the economy meant, despite many who wished to the contrary, that expansion would be limited, at least within Moravian Bethlehem proper.

Expansion would come to Bethlehem, but it would be in those areas adjacent to the original Moravian community, which are known today as West and especially South Bethlehem, wherein outside forces increasingly came to play a critical role. The discovery of coal in northeastern Pennsylvania led to the need to ship this product in a more cost-effective way. In 1815, the first coal yard was established along the Lehigh River. In 1822, the Lehigh Coal and Navigation Company was incorporated, and in 1818, the Lehigh Canal opened to carry coal to the Delaware Canal for further shipment to Philadelphia. The coming of the canal created a new set of economic conditions as non-Moravian entrepreneurs established hotels, stores, and support businesses on property surrounding Moravian Bethlehem because the policy of exclusivism still existed within Bethlehem. The increasing economic activity forced church leaders to rethink the system of exclusivity, which was gradually modified, as restrictions on private enterprise were lifted and finally in 1845, the lease system was terminated. The church sold off its major land holdings, and non-Moravians could own property for the first time. On August 9, 1845, the voters of Bethlehem approved the reorganization of their community into a borough. However, it would be the establishment in South Bethlehem in the late 1850s of the Bethlehem Iron Company, the forerunner of the Bethlehem Steel Corporation (1904), that would most dramatically recast the technological image of the community. No longer the quaint and "curious" communal town of Adams' day, Bethlehem was fast becoming one of the region's, if not, indeed, the nation's, leading "gritty" cities. It was, however, an industrialization that took place outside the original bounds of Moravian Bethlehem.

During this period of transition, the industries that had once thrived in the colonial industrial quarter eventually fell victim to economic change. The oil mill stopped production in 1814, with only the snuff mill and a buckwheat milling operation that would last until 1876 still in operation. In 1832, the water system for Bethlehem was relocated from Christensen's 1762 waterworks to his later oil mill building, where in 1868 steam power would be added to power the pumping system until 1912 when the spring, which had served Bethlehem since its founding, was declared contaminated. The tannery stopped production in the 1870s due to the high cost of shipping tanbark to the site. Grist milling continued on the site of the original 18th century mills, although after 1869 in a new brick building that replaced the 1752 stone mill destroyed in a fire. The tawery ceased production at some point during the second quarter of the 19th century and was eventually converted into a beer hall, bowling alley, and concert hall. Most of these original buildings became multi-family dwellings and eventually fell into disrepair and disrepute until they were finally torn down for the good of the community. Thus had this once proud industrial area containing "a fine sett of Mills," which according to Adams were "the best ... that are any where to be found," finally fallen. It would not rise again until a new economic development in the 1960s and 1970s called heritage tourism created opportunities for research and restoration that would enable future generations to learn about the industrial past.