Medieval Treadwheels: Artists’ Views of Building Construction

ANDREA L. MATTHIES

The hoisting machines used to erect the great churches of the Middle Ages can be known only imperfectly from existing archival sources and archaeological remains. However, two other sources can supplement our understanding. First, medieval manuscript illuminators provide visual information about the development and structure of hoisting machines—from the simple windlasses to the great treadwheels. Although constrained by the narrative tradition, patronage, and stylistic limitations, these painters are a valuable source, if used critically. Second, the living social archive of the workyard—that is, modern workers who have used these ancient machines—offers additional insights into their usage. Although they remain imperfect sources, the archives, archaeological remains, manuscript illuminations, and builders used together will enrich our knowledge of medieval hoisting machines.

A purely archival approach is limited by the uneven survival of documents and by problems of interpretation. The terminology used in building accounts (or fabric rolls) and contracts is often general and ambiguous. Clerks of the works, who recorded expenditures for labor and equipment, lacked a standardized vocabulary for the new tools and machines being introduced into the workyard. Hence, we must

Dr. Matthies is a medieval art and architectural historian working as an independent scholar. She is currently writing a comedy about lawn ornaments. The original research for this project was partly funded by a Chester Dale Fellowship from the Center for Advanced Study in the Visual Arts, National Gallery of Art, Washington, D.C. The University of Michigan, Dearborn, provided a grant for the purchase of photographs. The author would like to express gratitude to William B. Voekle of the Pierpont Morgan Library and the curators of the British Library in London and the Bibliothèque nationale and Bibliothèque Ste.-Geneviève in Paris. She is particularly indebted to Bert S. Hall of the University of Toronto for material on medieval technology and for his encouragement, to David R. Green of Kings College, London, for the work on 19th-century treadwheels, to Leo A. Matthies for tutorials in engineering, and to James J. Odell for help in physics and mathematics. This article is dedicated to the memories of Edith Cooper of Endwell, New York, and Keith Entwistle of Canterbury, Kent.

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infer from context the meaning of the general terms ingenium, machina, and tornamentum that appear so often in these texts. Ingenium, for example, implied no more than a clever invention. This custom of referring to lifting devices by a generic term complicates the exploration of archival sources to chart the development of the windlass and treadwheel.

Archaeological remains of these machines, though comforting in their solidity, are equally problematic. Extant windlasses and treadwheels do provide information about basic configuration and size. (See the Appendix for a listing of extant windlasses and treadwheels.) However, some are fragmentary or heavily restored, and most date from the later Middle Ages. The current placement of hoisting machines reflects their final resting spot, which was not necessarily their location during construction. Many are no longer hooked up to their original pulley systems.

Manuscript illuminations, used critically in connection with archival and archaeological sources, can help clarify the development and use of treadwheels and other hoisting devices on medieval construction sites. However, manuscript illuminations remain a controversial source. Since scholars have differed considerably in their assessment of this visual resource, a brief analysis is needed of the strengths and weaknesses of these illuminations as a supplementary resource for medieval construction technology.1

1In L. F. Salzman, Building in England Down to 1540 (Oxford, 1952), the illustrations from manuscript illumination are a mere appendage to the text. John Harvey, Medieval Craftsmen (London, 1975), has more heavily illustrated his work, although his approach relies on documentary sources to establish a date for a given machine or tool. Lon R. Shelby, “Medieval Masons’ Tools: The Level and the Plumb Rule,” Technology and Culture 2 (1961): 127–30, and “Medieval Masons’ Tools. II. Compass and Square,” Technology and Culture 6 (1965): 236–48, is more enthusiastic about the use of pictorial material. In France, DuColombier calls pictorial sources documents figurés, although he does not provide a critical methodology. See Pierre DuColombier, Les Chantiers des cathédrales (Paris, 1953), p. 107. Marcel Aubert’s position is similar: see “La Construction au moyen âge,” Bulletin Monumental 118 (1960): 241–59, and 119 (1961): 7–42, 81–120, 181–209, 297–323. Günther Binding and N. Nussbaum, Der mittelalterliche Baubetrieb nördlich der Alpen in zeitgenössischen Darstellungen (Darmstadt, 1978), have cataloged scenes of building construction, basing their work on that of a Belgian scholar: Frieda van Tyghem, Op en om de Middeleeuwsse Bouwerf, 2 vols. (Brussels, 1966). For each image from various media, Binding and Nussbaum provide the date and provenance, the manuscript’s name, and a list of tools and machines depicted. No critical analysis of the paintings or relief carvings is made. Their essay is based on the assumption that these images, ranging from the 12th to the 15th centuries, mirror contemporary reality. They make no attempt to deal with art-historical problems, the implications for using these images as a source for technological history, or the relationship between the imagery and contemporary archaeological and archival sources. No Italian material is included.
We must remember that medieval artists were basically illustrating narratives—some of which happened to include building construction. For example, the founding of Rome illustrated in an *Histoire universelle* might emphasize the political strife and use the scene of building construction as a mere backdrop for the drama of fratricide. This emphasis on social and political events stems from another constraint on medieval artists—the system of manuscript patronage. Since these artists were not working for themselves, their work had to reflect the preoccupations of their patrons. Aristocrats were usually more interested in seeing illuminations of elegantly attired noble patrons admiring construction sites than appreciating an attentive rendering of machines and workers' activities.

Stylistic constraints were also important. Artists were breaking from the principally symbolic expression of the Romanesque era and entering the phenomenal world of the Gothic. In their struggle with the techniques of naturalistic representation, they developed an empirical approach to perspective schemes using relative proportions. They also included fresh observations of the world in traditional scenes. Indeed, their introduction of treadwheels to illuminated construction sites by 1240 dramatically demonstrates this growing empiricism. Treadwheels are difficult to draw, however, unless shown completely in profile as in the earliest examples. This view can be drawn easily with a compass and straightedge. In views from other angles, even when artists used rudimentary forms of perspective, the elliptical form of the treadwheel, the pattern of spokes and struts, and the added complication of human figures combined to create a challenging design problem. One artist even omitted the spokes, so that the human figures could be easily viewed.\(^2\)

Artists' exploration of the world was also hindered by available tools. Until the 15th century, paper was scarce and parchment expensive. New ideas had to be worked out on scraps of parchment or on wax tablets. For observations stored in the mind's eye, even the most talented artist would generalize a new and structurally complicated item like a treadwheel. The treadwheels' location also hindered study by artists, since the machines were frequently mounted under the completed roofs of cathedrals. Here, they were not visible to passersby and were obscured to closer scrutiny by the dim light under the roof.

Despite these limiting factors, some gifted and adventuresome artists did explore the workyards of medieval construction sites. Their

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forays are evidenced principally by their breaks with artistic tradition. Illuminators introduced new building tools and machines into their descriptions of construction. For example, they showed stone being carved by mallet and chisel and materials being raised by newly invented hoisting devices. Moreover, these artists frequently rendered certain idiosyncrasies of building construction peculiar to their regions; for example, the design and materials of the hod varied considerably from one part of Europe to the other but tended to be consistent within each region.

To support this analysis of the medieval artistic perception, I gathered 339 images primarily from western European manuscripts of various religious and secular texts. These manuscripts date from the 12th to the beginning of the 16th century, a chronological range that permits a comparison between Romanesque and Gothic and between northern and Italian Renaissance imagery. This broad geographic and chronological range makes possible the analysis of trends in the response to this new technology. We can discover which regions of Europe produced artists with a curious eye toward changes in building construction. By analyzing the work of exceptional artists who broke with tradition, we can compare their work with archaeological and archival evidence in this study of the medieval treadwheel.

Historical Background

Both archival and archaeological sources tell us that the Romans used mechanical hoisting devices. Vitruvius in De Architectura (X, 2, 1–10) gives a lengthy account of two types of crane, one with a single-beam jib and the other with a double-beam jib. In addition, two Roman relief panels from the 1st century A.D. depict treadwheels. The entire catalog of images is part of a broader study of medieval building construction and artistic perception and is printed in my dissertation: “Perceptions of Technological Change: Medieval Artists View Building Construction” (State University of New York at Binghamton, 1984). For each manuscript, data were tallied giving the manuscript’s library signature, provenance, the text and its author, the manuscript’s patron, and pertinent characteristics of the manuscript. For each image, the folio number, format, and subject matter were noted. Then a more detailed analysis was made of the kind of building shown under construction, the various aspects of construction depicted, and the kinds of tools and machines used. This was followed by a technical critique of the artist’s description of building construction. Next, the workyard hierarchy was scrutinized, and the relative size and social status, dress, and gestures of the main characters were recorded. Finally, the images were analyzed stylistically for the degree of illusionism and the dominance of pictorial concerns over an accurate description of the site.

The example from the Lateran Museum shows a wheel of simple, spoked construction operated by two men charging up the slope of the inner rim. A more elaborate relief in the Vatican Museum from the Tomb of the Haterii has a Vitruvian-style treadwheel being used to construct a mausoleum. The wheel's design is similar to the treadwheel in the Lateran relief with spokes radiating out from a thick central shaft, with no additional struts. Also similar, but compounded here, is the inefficient use of the machine, as described by the sculptor. Attempting to increase the illusion of activity, both artists have lined up workmen one behind the other inside the treadwheel. The Lateran relief has two men, the Vatican relief at least five. Such a gang adds drama, but reduces the mechanical advantage, since the weight of the men in back detracts from the effort of the men in front.

The treadwheel fell into disuse in western Europe during the early Middle Ages. That stone was carried by hand then is apparent from the relatively small building blocks. The reemergence of mechanical lifting devices received its most famous notice by Gervase of Canterbury when he described the rebuilding of Canterbury Cathedral after the disastrous fire of 1174. However, while he extolled at length the artistic skill and ingenuity of William of Sens, Gervase did little more than note that this master builder also "constructed ingenious machines for loading and unloading ships, and for drawing cement and stone." Later, Gervase described the work that preceded the terrible fall of Master William of Sens. "In the beginning of the fifth year, after he had completed the triforia and upper windows on both sides, he was preparing machines for the turning of the great vault." We have no more specific information on the structure or complexity of these machines, except to note that tornamentum implies winding. John Harvey has suggested that this term implies the use of a windlass or type of derrick or crane rather than a screw.

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8von Schlosser, p. 262: "Peractis autem utrique triforiis et superioribus fenestris, cum machinas ad fornicem magnam volvendam in anni quinti initio praeparasset."
9Harvey (n. 1 above), p. 102.
English Close Rolls contain numerous references to machina and ingenium from the 13th century. In June 1222 at Winchester Castle, tallow was purchased for lubricating the engines used to hoist timber and water.\textsuperscript{10} In 1233 roof timbers at Winchester Castle were raised by windlass or crane.\textsuperscript{11} At Flint, grease was purchased in 1285–86 for lubricating a crane, “pro quadam machina,” being used to lift joists in one of the towers facing the river.\textsuperscript{12} A different term appears at Westminster in 1264 in connection with constructing the church and king’s buildings: “windagio et cariagio,” that is, payment for the windage and carriage of materials being hauled and raised.\textsuperscript{13} In 1331 a large cable of hemp was purchased to raise the stones by windlass during the construction of the Westminster Palace chapel.\textsuperscript{14}

Specific mention of a treadwheel (magna rota) first appears in archival literature in France about 1225. In England, the documented use of the treadwheel does not appear until the 14th century. In 1331 the authorities at Merton College spent 2d. on “drink for the men (garcionibus) on the day when the wheel was removed.”\textsuperscript{15} At Abingdon Abbey timber was purchased for the great wheel (magna rota) in 1375–76 at a cost of 12s.\textsuperscript{16} At Oxford the great wheel in the tower of New College was repaired in 1396.\textsuperscript{17}

The process by which the Roman treadwheel was reinvented during the 13th century is not recorded. Structurally and mechanically it evolved from the windlass. Since these earliest windlasses have disappeared, pictorial sources are particularly valuable for tracing their structural evolution. Most clearly related to the era of William of Sens at Canterbury is an English depiction of a windlass in the Vitae Offarum, dating about 1250\textsuperscript{18} (see fig. 1). Although made seventy-five years after William’s work at Canterbury, this drawing describes a simple ingenium. Four spindly arms radiate from the machine’s shaft,
Fig. 1.—This northern European-style windlass with radiating spokes is mounted upright so it can be worked from a standing position. Matthew Paris drew this building scene around 1250, showing, in addition, plumblines, levels, axes, and adzes. (Vitae Offarum, TCD MS 177 [formerly MS E.i.40], fol. 60r, Trinity College Library, Dublin; courtesy of the Board of Trinity College.)
FIG. 2.—The Italian crank-style windlass required more bending than the northern spoked style. This 15th-century fresco also reflects Italian artists’ emphasis on showing the human form in extreme postures: *Foundation of Alessandria della Paglia by Pope Alexander III*, by Spinelli Aretino, Sala della Balia, Palazzo Pubblico, Siena. (From Richard A. Goldthwaite, *The Building of Renaissance Florence* [Baltimore, 1980], fig. 137.)

which is mounted on two short, braced posts. The arms of this basic windlass are being pulled by one man standing upright. The rope runs over a T-shaped crane and is being used to raise aloft a wicker basket with a thick handle. This type of windlass remains constant in British and northern European illumination during the 13th and 14th centuries with only minor variations in the number of spokes and slightly different patterns of bracing.

While northern pictorial literature consistently shows the spoke-handled windlass, Italian artists are generally reluctant to include any hoisting machinery at all in their scenes of building construction. When they do, they prefer the crank-type windlass. This crank-type windlass appears in a 15th-century Sienese fresco painting by Spinelli Aretino19 (see fig. 2). The windlass sits on a triangular wooden frame.

19Another double-cranked windlass shown mounted aloft is pictured in Richard A. Goldthwaite, *The Building of Renaissance Florence* (Baltimore, 1980), p. 151. The work by the Master of San Miniato (fl. 1460–80) depicts St. Barbara having the fatal third window added to her tower.
Its long, thin shaft is only waist-high, and the workmen must bend over deeply to turn the cranks at both ends. Work at this machine would be more tiring than work at the northern spoked windlass, which is customarily shown mounted at a comfortable height. However, the extreme bent-over posture shown in the Italian fresco may be, in part, a visual metaphor for effort rather than a direct transcription of workyard practice. It also reflects Italian artists' obsession with the human form posed in extreme attitudes.

According to Lynn White, a major mechanical refinement of the crank adds a flywheel to "smooth out irregularities of impulse and get over 'dead-spots.' "20 He also notes that the first archival reference to the flywheel21 appears in the treatise of Theophilus Presbyter (dated 1122–23).22 In De diversis artibus, the author describes the equipment, ingredients, and processes required to make precious metal objects, stained glass, and illuminated manuscripts. His flywheel is attached to the axle of a small mill used for grinding gold powder.23 Two centuries later the principle of the flywheel is analyzed by Jean Buridan. In his treatise he makes an observation regarding impetus—a rotary grindstone continues turning well after force is removed.24

An elegantly drawn windlass with a flywheel is placed at the foot of the Tower of Babel in the Bedford Hours, ca. 143025 (see fig. 3). This double-handed crank is solidly mounted on a wooden base and placed high enough from the ground so that the two laborers need not bend over far. The crank's design is very similar to one drawn by Leonardo da Vinci.26 Though the Bedford Hours reflects the Franco-Flemish tradition, the artist is generally keen to include Italian elements in both an archaeological and a pictorial sense. For example, he includes both a Flemish and an Italian plane in the scene.


21 White, Medieval Technology and Social Change, p. 115.


23 John G. Hawthorne and Cyril Stanley Smith, On Divers Arts: The Treatise of Theophilus (Chicago, 1963), p. xvi, also include a drawing by Theobald reconstructing this machine in fig. 1.


25 In his discussion of the double-handed crank, White (Medieval Technology and Social Change, p. 171, n. 7) notes the carpenter's brace in an adjacent illumination of Noah's ark. However, White does not refer to this double-handed crank with flywheel in the scene of Babel.

of Noah building the ark. This crank-style windlass probably reflects an Italian tradition, since it does not appear in any other northern manuscript.

A later windlass design may indicate an advance on the simple, spoked windlass and may be an intermediate step between that and
the treadwheel. It was even used after the treadwheel was developed. In the 15th century this type is found in Franco-Flemish illuminations and in the first part of the technological treatise of the so-called Anonymous of the Hussite Wars, dated 1472–75. In a Flemish Book of Hours (fig. 4), the windlass is shaped like a ship’s wheel with spokes

The men stand upright pulling the shafts and easing an ashlar block into position in a fine example of team effort. The wheel is attached to a sturdy, well-studied crane. The machine in the Hussite manuscript differs slightly from that in the Flemish manuscript. The spokes originally projected sideways from the outer rim. As for the mechanical efficiency of this variation, Bert Hall notes that the inscribed wheel would “increase the moment of force slightly, but the stress on the wheels would be considerable.”

The extant windlasses at Peterborough (fig. 5) and Tewkesbury are similar to the design shown in these manuscripts, in which a rim extending beyond the rim. The wheel with a similar structure is used to construct a remarkable Gothic rendition of the Pantheon. See Copenhagen, Kongelige Bibliotek, MS de Tooth 568, fol. 1r, pictured in DuColombier (n. 1 above) (2d ed., 1973), fig. 73.

Hall, fol. 1r.

Ibid., p. 139, n. 2.
encloses spokes that radiate from the axle.\textsuperscript{31} The placement of the outer spokes, though, resembles the example from the Hussite manuscript. Both windlasses originally had rungs or staves projecting from both sides of the rim of the machine. William Backinsell believes that men worked the windlasses by climbing these rungs on the outside of the wheels.\textsuperscript{32} Operating the machine this way would require extremely sure footing, made even more difficult by the bulky pattens a laborer would have to wear in order to walk on rungs for any length of time. This machine could, as well, have been operated manually with one or two men pulling the rungs hand over hand. In his 15th-century treatise, Taccola describes a similar windlass with a ladder rim operated by one man pulling the rungs with his hands.\textsuperscript{33}

The dating of the Peterborough and Tewkesbury windlasses is problematic. Because they are located in Norman towers, Backinsell places them both in the 12th century.\textsuperscript{34} Cecil Hewett regards this as inadequate proof and recommends a carbon-14 dating.\textsuperscript{35} L. F. Salzman dates the Peterborough windlass as 13th century.\textsuperscript{36} This debate over precise dating is not as significant as the relative position of these windlasses within the development of hoisting machinery. One can at least conclude that these two machines represent an early phase of development.

The windlass in the spire of Salisbury Cathedral (fig. 6) originally had a structure similar to the Peterborough and Tewkesbury windlasses. A ladder-like rim encompasses spokes radiating from the central shaft. However, several additions were made to the original design. First, the staves that project from the outer rim are sandwiched between two more rims. Then, while only four shafts penetrate the axle, four more were added by essentially augmenting the axle. Finally, planks were laid on the inner circumference of the wheel, providing a surface for interior treading. Nevertheless, the wheel's diameter of 10 feet, 10.5 inches, makes walking inside the wheel crook-necked work even for a person of average height. Roy Spring, the clerk of the works, indicates that the windlass is still used

\textsuperscript{31}Figures 2, 3, and 4 in William G. C. Backinsell, "Medieval Windlasses at Salisbury, Peterborough, and Tewkesbury," \textit{South Wiltshire Industrial Archaeology Society Historical Monograph} 7 (1980), are measured drawings of these machines.
\textsuperscript{32}Ibid., p. 4. Hall (n. 27 above), p. 168, fol. 20v, includes an illustration of a grain mill, propelled by a man walking on the staves that radiate from the outer rim of a wheel. He is shown supporting himself by holding two handles at the top of the frame.
\textsuperscript{33}Frank D. Prager and Gustina Scaglia, \textit{Mariano Taccola and His Book De Ingenieis} (Cambridge, 1971), fig. 113.
\textsuperscript{34}Backinsell, p. 4.
\textsuperscript{36}Salzman (n. 1 above), p. 325.
Fig. 6.—Originally designed like the Peterborough windlass, the 13th-century Salisbury Cathedral windlass later had four extra spokes added and planks laid on the inside surface of the wheel's circumference. These additions made it a small (just under 11 feet in diameter) treadwheel. (Courtesy of A. F. Kersting, London.)

and dates it as late 13th century, although Hewett places it in the period of the tower's construction, 1220–58. These dates can be debated, but the machine is more significant for what additions to its structure reveal about the evolution of the windlass. When the machine was strength-

38Hewett, p. 70.
ened for heavier work, the resulting structure fell between earlier windlasses, such as those at Peterborough and Tewkesbury, and later treadwheels.

The treadwheel's appearance on construction sites in the mid-13th century represents either the final step in the technological evolution of the windlass or a resourceful reinvention of the Roman machine. The impact of Vitruvius is hard to calculate, although *De Architectura* was available in many monastic libraries. The development of the treadwheel may have been aided by the collaboration of a mechanically minded cleric, who had read Vitruvius, and an inventive master builder like William of Sens. The reinvention of the treadwheel may have been prompted, as well, by people observing the labor-saving principles of the waterwheel, which by the 13th century was found throughout Europe. This idea is reinforced by the structural similarities between the early treadwheels and contemporary waterwheels.

Archival and pictorial evidence suggests that the treadwheel was adopted only sporadically across Europe and Great Britain. Although the first archival reference comes from France in 1225, the treadwheel is not recorded in England until 1331. Artists were equally slow to include the treadwheel in their work: only three appear in the 13th century and five in the 14th, increasing to fourteen treadwheels in the 15th century. The remainder from the base of 339 images date to the early 16th century.

*The Structure of the Treadwheel*

The medieval treadwheel, referred to in building accounts as the *magna rota*, is just that—a large wheel from 14 to 16 feet in diameter with a treadmill inside, generally wide enough for two people walking side by side (see fig. 7). The rim of the great wheel is connected to a thick central shaft by struts and spokes in varying configurations. The thick hemp rope, used to haul objects aloft, coils continuously along the central shaft, which is about 1 foot in diameter and projects

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39 Salzman, p. 325, documents the association of *magna rota* with a wheel having a treadmill. At Clarendon in 1488, money was paid “to four men running in the great wheel for four days.”
40 The rope at Canterbury’s treadwheel is about six inches in diameter. By the 15th century, Brunelleschi’s hoisting machines at the Duomo in Florence could wind a rope about 600 feet long that weighed 1,100 English pounds and could support about 10 to 15 English tons. Frank D. Prager and Gustina Scaglia, *Brunelleschi: Studies of His Technology and Inventions* (Cambridge, Mass., 1970), p. 72, n. 10.
Fig. 7.—Canterbury Cathedral's treadwheel in the Bell Harry Tower has a clasp-arm design and dates to the late 15th century. Generally propelled by one laborer, it could accommodate two for heavier loads. This user-friendly machine hauled materials aloft until the 1970s. (Courtesy of W. L. Entwistle, Canterbury.)

outward to one side.\textsuperscript{42} The entire apparatus is secured within a massive framework of balks.

Hewett has differentiated two types of connections between the spokes and central shaft: one called the “compass-arm” wheel and the

\textsuperscript{42}Salzman, pp. 327–28.
other the "clasp-arm" wheel. In the compass-arm type, the spokes are driven directly into the shaft, in a greatly magnified version of a wagon wheel. In the clasp-arm type, the arms are arranged as chords to the wheel rim (see the Canterbury treadwheel in fig. 7). The primary pairs of arms flank a squared portion of the shaft and reach across the wheel's diameter. Secondary pairs of shorter arms extend from struts that brace against the primary arms near the shaft. In the Canterbury treadwheel, these struts become handholds for the laborer walking the wheel. The shaft has a round profile where the rope coils.

The clasp-arm type has several advantages. It reduces stress on the central shaft, since the shaft is not punctured around its circumference where the arms are inserted. An additional advantage is the possibility of using a thinner shaft. Structural stability for heavy loads is achieved through the arrangement of arms and struts. Villard de Honnecourt's Sketchbook, dating about 1235, provides a rare glimpse at a contemporary design. The design has elements of both the compass-arm and clasp-arm types. While Villard recognizes the potential weakness of the compass-arm type, his solution only adds extra buttressing at the axle (fig. 8).

The earliest illuminated depictions of the treadwheel date from 1240, shortly after its first archival reference. They consistently show the compass-arm type. Among these is the Tower of Babel in the lavishly illuminated Morgan Old Testament (fig. 9). The manuscript's origins are not precisely documented, though it is probably French. The Morgan wheel is a simple structure with the wheel's axle secured on two upright posts, braced at midpoint. Eight spokes radiate evenly from the axle. The machine is set up on what appears to be scaffolding that projects just below the tower's construction zone. The wheel is attached to a verna, an inverted L-shaped structure with pulleys both at the angle and the projecting end, and braced by a diagonal strut. The load is being raised on a pallet, resting in a rope sling and suspended from the crane's hook. Underneath the pallet is a conspicuous loop, securing a thinner rope held by a workman at ground level to keep the load from swinging disastrously from side to side.

This careful description of the use of construction tools and machines contrasts with the relatively abstract pictorial style. Details of the work are placed within a schematic setting. The contrast creates

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43Hewett, p. 67.
44Backinsell (n. 31 above), p. 8.
certain anomalies. For example, the laborer inside the wheel stands almost to its diameter. Quite likely, this reflects the pictorial device of using one scale for people and small objects and another for large objects and buildings. It should not be viewed as a literal rendering of scale.\(^4\) In addition, despite the labor-saving treadwheel, a hod carrier and stretcher-bearers still carry building materials aloft. Indeed, one curious aspect of these construction scenes is the juxtaposition of “old-fashioned” tools, machines, and techniques with newly invented ones.\(^4\) However, while this illuminator included both kinds of hoisting devices, he clearly celebrates the new lifting device by contrasting the postures and gestures of the laborers. The bent-over posture of the stretcher-bearers and hodman contrasts vividly with the upward-turned head of the man in the treadwheel. He strides vigorously, refueling with a fistful of bread while the others plod. In addition, one can hardly escape the possibility that the artist has created a visual pun

\(^4\)Some of the earliest wheels were possibly converted windlasses like that at Salisbury.\(^4\) Another such example is the persistent tradition showing two sets of masons on the same site: one taking axes to fine-cut stone, the other using mallets and chisels. The latter were noted by Gervase of Canterbury as yet another innovation in the choir reconstruction.
FIG. 9.—This illumination of the Tower of Babel celebrates the new technology by contrasting a compass-arm treadwheel with heavily burdened hod carriers and stretcher-bearers: M638, fol. 5r, Pierpont Morgan Library, New York. (From Sydney C. Cockerell, Old Testament Miniatures [New York, 1969], fol. 3r, detail.)
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by “resting” the scaffolding on the stretcher-bearer’s head. This artist conveys both careful observation of technology and a positive attitude toward its more innovative aspects.

The structural weakness of the compass-arm type was finally remedied with the clasp-arm treadwheel. Hewett claims that the clasp-arm treadwheel was first illustrated in 1556 and probably invented shortly before this date. However, the treadwheel in the Bell Harry Tower of Canterbury Cathedral (fig. 7) is the clasp-arm type and dates to the late 15th century. Actually, pictorial evidence points to a much earlier invention of the clasp-arm type—shortly after 1380. The carefully studied illustration of the Tower of Babel from a Bohemian Bible clearly shows the clasp-arm treadwheel (fig. 10). The treadwheel design, showing two pairs of arms flanking the shaft, breaks with pictorial tradition and therefore suggests empirical observation. Somewhat later, the clasp-arm type can be found in drawings of Brunelleschi’s hoisting machines, designed between 1420 and 1435 for his work at the Duomo in Florence. Thus, both archaeological and pictorial evidence support a considerably earlier date for this structural improvement in the treadwheel.

As hoisting machines became more mechanically sophisticated, the supports for the pulleys became more structurally complex. In the simplest version, the pulley hooked on the framing balk of the treadwheel or on the end of a putlog. Artists occasionally mounted pulleys on the picture frame, creating a visual pun (fig. 2). A more complicated pulley support had the picturesque name of verna in Latin and fauconneau in French. This was a stout vertical shaft that was mounted on the building. It carried a pivoting horizontal beam called the “hawk” or “falcon” with the pulley secured at the end. In 13th- and 14th-century illuminations, the hawk perching on the shaft is shaped like a T or an inverted L (fig. 9). The structural effectiveness of the trusses, used to support the hawk, varies considerably. While a pulley is invariably shown at the projecting end of the hawk, artists sometimes omit the intermediate pulleys. In addition, the rope’s passage occasionally defies logic. The pulleys (made of bronze or iron) are consistently shown as simple pulleys with no compound pulleys or tackle blocks to increase their efficiency.

4Hewett (n. 35 above), p. 67.
49Prager and Scaglia, Brunelleschi, fig. 12.
5For a more elaborate discussion of the development of the crane, see Fritz Toussaint, Lastenförderung durch fünf Jahrtausende (Mainz, 1965); and Michael Matheus, Hafenkrane: Zur Geschichte einer mittelalterlichen Maschine am Rhein und seinen Nebenflüssen von Straßburg bis Düsseldorf, Trier Historischen Forschungen, Bd. 9 (Trier, 1985).
51Salzman (n. 1 above), p. 324.
Fig. 10.—This double treadwheel was more commonly found at seaports, where its added power was useful for unloading ships: Tower of Babel, 1380, Biblia Wenceslai Regis IV, Cod. 2759, fol. 10r, Nationalbibliothek, Vienna. (From Vaclav Husa, Josef Petran, and Alena Subrtova, Traditional Crafts and Skills [London, 1967], pl. 90.)

The more structurally sophisticated jib-arm crane was found in ports by the 14th century, and its use was widespread by the 15th century.\textsuperscript{52} Harvey describes its structure as derived from the “oblique

\textsuperscript{52}Ibid., p. 326.
yard used on lateen-sailed ships, forming a jib. It moved from seaports, where it was used to load and unload ships, to construction sites. Here, its distinctive profile became the most telling sign of construction (fig. 4).

The loads raised by these cranes and hoisting machines were either hauled up directly or placed in containers. Ashlar blocks were raised either by sling (fig. 3), clamps (figs. 4 and 10), or lewis. Artists were reluctant to show ashlar blocks being raised by lewis. Once a lewis is embedded in a block, its three-part workings are only evident when viewed close up. The operation of slings or clamps is more obvious. Other objects being raised aloft are placed on a pallet (figs. 9 and 11) or within a sturdy basket (figs. 1 and 10), wooden box, or barrel (fig. 3). These are then attached to the thick rope of the treadwheel and usually guided aloft by another thinner rope suspended from the pallet or carrier box (figs. 9 and 11).

Pictorial sources provide valuable evidence about medieval treadwheels for which we lack archaeological remains or archival references. One such example is the double treadwheel, which has one wheel at each end of a single axle and carries materials for a single crane. Being attached to the same axle, the wheels rotate together. While double treadwheels were found on the docks, they may have also been used on construction sites. Such double treadwheels are described in the Bohemian manuscript, noted above for its precocious description of the clasp-arm treadwheel design (fig. 10). The entire apparatus with its double treadwheels seems geared to loads heavier than normal. Since the wheels rest on putlogs cantilevered from the wall, thick walls would be needed to support the machine. Doubling the load size of materials being raised to the construction zone was probably not efficient. Since early cranes did not pivot, large loads would have piled up rapidly. Moving materials to the construction zone was generally limited by the speed with which the workers could utilize the material. This is probably the most important reason for the predominance of the single treadwheel in medieval construction.

54Salzman, p. 322.
55Another Bohemian manuscript, dating 1411, includes a similar double treadwheel, though its artist is less skilled in drawing machines. See Litoměřice, State Archives, Litoměřice Bible, fol. 114, published in Vaclav Husa, Josef Petran, and Alena Subrtova, Traditional Crafts and Skills: Life and Work in Medieval and Renaissance Times (London, 1967), pl. 95. The Hussite manuscript also includes illustrations of construction machinery with double treadwheels. See Hall (n. 27 above), fols. 1r and 8v.
FIG. 11.—This Tower of Babel shows an early example of a slewing crane, which allowed rotation of the load: 1340, Velislav Bible, Sign Lob 412, MS 23 C 124, fol. 11v, University Library, Prague. (From Pierre DuColombier, Les Chantiers des cathédrales, 2d ed. [Paris, 1973], fig. 13.)

Placement of the Treadwheels

The original placement of these windlasses and treadwheels can best be analyzed by combining archaeological and pictorial evidence. All extant hoisting machines in England are located in the towers of large churches above the vaulting and below the roof. They remained
there after the building construction was completed to raise materials for subsequent repairs. Backinsell suggests that abandoning them was cheaper than dismantling them. Yet the present site of these hoisting machines tells us little about their location during construction.

Pictorial evidence and an astute analysis of building construction by Thomas Watson suggest that windlasses (and later treadwheels) were located at ground level inside the structure for the initial stages of large church construction. He cites several reasons. First, the walls of these Gothic churches were thin, incapable of supporting the combined weight of the heavy treadwheel and pallets of large ashlar blocks. Also, the walls were too narrow for the "wide-straddling legs" required of the treadwheel.

Normally, the treadwheel was not used aloft until the massive tie beams of the roof connected the walls. Then it could be mounted on the roof beams and moved from bay to bay during construction of the vaults, as described in the archives at Westminster Abbey. Moving these heavy machines was made easier by prefabrication, which was also true for many other medieval wooden structures, including houses. Markings on key joints of the Canterbury treadmill indicated how the sections were reunited. Thus, the machine could be dismantled totally or in part, when moved.

Additionally, until the mid-14th century or even later in some parts of Europe, these hoisting devices were capable solely of a vertical lift. Horizontal movement was not possible. This meant that blocks had to be raised directly into place. This could be accomplished two ways. Either a windlass or treadwheel would rest at ground level with a portable verna secured to the construction zone aloft, or a lightweight (and therefore mobile) hoist would perch at the construction zone.

Not until the mid-14th century do we have pictorial evidence of a clearly pivoting crane attached to a treadwheel. No archaeological evidence of such a crane survives, possibly because most extant treadwheels are located in the upper zone of towers, where the pulley is fixed to the treadwheel's frame directly above a trapdoor. However, a pic-

5Backinsell (n. 31 above), p. 4.
58Fitchen, p. 306.
60An excellent example of this kind of assemblage is still visible in the roof timbers of the Chapter House at York Minster.
61Watson, as cited in Fitchen, p. 306.
torial description of a slewing crane appears as early as 1340 in the Bohemian Velislav Bible (fig. 11). One of the treadwheel’s support balks extends upward and tapers to a sharp point. Mounted on this point is a tilted T-shaped crane with pulleys at both ends. The crane is further supported by a bracket, clearly shown to encircle the thicker portion of the shaft. The possibility of rotation is further suggested by the fact that this artist usually locks joints into place with conspicuous nails, which he omits from this particular bracket. About 150 years later, the slewing crane is shown in the treatise of Anonymous of the Hussite Wars. \(^6^2\)

The last factor limiting the use of hoisting machinery in medieval building construction was the extremely lightweight scaffolding used. \(^6^3\) The scaffolding itself was only strong enough to support the workers and whatever load they carried. It simply could not hold the weight of the treadwheel and its load. The walls themselves provided passageways for the builders and secured the putlogs on which the hurdles rested. In describing scaffolding, medieval painters generally show putlogs covered with either hurdles or planks (found more often in German or Austrian manuscripts). Complex pole scaffolding rising from the ground is found in several 15th-century Flemish manuscripts and 16th-century Italian manuscripts. This scaffolding is trussed and therefore more stable. The structural problems of verna and cranes are similar, and alert artists generally notice both.

Pictorial evidence for the placement of hoisting machines complicates matters, because of certain artistic conventions that remain fairly constant from the Middle Ages to the Renaissance. Buildings under construction are usually shown from the outside, perhaps because building exteriors provide a more comprehensible profile than a portion of the interior. In addition, though medieval construction sites may have been more open than modern sites, they were still likely closed to the public. Theft of tools and portable materials was a problem even then, as one can read in the building accounts. Artists may have found the study of these interior-mounted treadwheels difficult and their depiction in this location undramatic. Thus, they chose to show most hoisting machines on the building’s exterior either aloft, on the ground, or occasionally mounted on the side of a wall.

An additional problem complicates using these illustrations to determine the original placement of hoisting machinery. Most tread-

\(^6^2\) Hall, fol. 8v, shows a construction crane that can pivot, although this example is much later—to 1472–75.

\(^6^3\) Fitchen, p. 286, details the difficulties in obtaining long-enough beams from as early as the 12th century by Abbot Suger of St. Denis. England, more abundantly endowed with forests, could be more prodigal in the use of the material.
wheels depicted are perched on the Tower of Babel. Of the twenty-nine treadwheels included in this study, fourteen are associated with the Tower of Babel. Of all the building projects described in the Bible and related histories of the world, the Tower of Babel remained incomplete and therefore is always shown under construction. In addition, the Tower of Babel—frequently cum magna rota—was a standard image in a history of the world that was very popular in Germany during the 13th and 14th centuries. Rudolph von Ems’s Weltchronik provides four of the six German illustrations of treadwheels in this study.\textsuperscript{[64]} The remaining scenes of the Tower of Babel in the Weltchronik include cranes with either a simple pulley system\textsuperscript{[65]} or an invisible, though presumably mechanical, source of locomotion for the crane mounted aloft.\textsuperscript{[66]} Once these new machines were associated with images of the Tower of Babel, artists’ tendency to copy one another ensured the treadwheel’s placement on the tower.

Treadwheels are also associated with towers because such structures really necessitate hoisting equipment to bring materials aloft. In these projects, the treadwheel’s location at the construction zone may reflect actual practice, as the machine could rest on massive beams spanning the crossing piers. Using a treadwheel mounted on the ground for the construction of a tower creates several hazards. First, the rope must be twice as long as the rope for a top-mounted machine. This doubles the length that must be inspected and maintained and increases the risks of the rope tangling as it coils. Second, as a load is brought aloft, the action becomes more critical as the load nears its destination. In these final stages, the movement must proceed smoothly and stop precisely. This can be achieved more easily if the person inside the wheel can hear the person directing the operations. Finally, if a load does get out of control, it can tumble disastrously on the men and machines set at ground level.

A few examples show these hoisting machines mounted on the outside of the wall with the framing balks of the machine resting on putlogs. The most notable of these is the Bohemian Bible with the

\textsuperscript{[64]} Stuttgart, Landesbibliothek, Cod Bibl MS 5, Weltchronik, fol. 9v; Zurich, Zentralbibliothek, Cod Rh 15, Weltchronik, fol. 6v; and Donaueschingen, Fürstlich Fürstenbergische Hofbibliothek, Cod 79, Weltchronik, fol. 11r. This historical epic, based on both the Bible and the Historia Scholastica of Petrus Comestor, was written by Rudolf von Ems, who died in 1251. Seventy-six known manuscripts of the Weltchronik are extant by a total of five different authors. The basic work on this text was done by Konrad Escher, 	extit{Die Bilderhandschrift der Weltchronik des Rudolf von Ems in der Zentralbibliothek, Zurich} (Zurich, 1985), p. 8.

\textsuperscript{[65]} Kassel, Landesbibliothek, 2 MS theo. Weltchronik, fol. 4r.

\textsuperscript{[66]} Berlin-Dahlem, Kupferstichkabinett, Cod. 78.E.1 Weltchronik, fol. 11r.
double treadwheel\textsuperscript{67} (fig. 10). Such a heavy machine would have to be mounted well below the construction level on very thick walls to secure its weight. Walls of this density would be more typical of castle or walled fortifications than cathedral construction. Proximity to the construction zone would make communications easier. On a cramped work site, this type of mounting would clear the area below, which could then be used for staging construction materials.

\textit{Mechanics and Usage of the Treadwheel}

In mechanical principles, the treadwheel represents an elaboration and improvement on the windlass. In its simplest form, the windlass comprises a horizontal drum and a hand crank. The mechanical advantage of the windlass can be increased by either reducing the diameter of the drum or increasing the length of the crank’s arm. The treadwheel, then, basically functions like an enormously augmented crank. The power generated by a person’s arm and shoulder is replaced by the greater power of a person walking within the wheel. The greater mechanical advantage of the treadwheel can be established mathematically through the formula $V/v = R/r$, where $V$ is the velocity of the crank, $v$ is the velocity of the weight being lifted, $R$ is the radius of the crank, and $r$ is the radius of the shaft.\textsuperscript{68} Thus a windlass that has a crank or spokes 16 inches long and a drum radius of 4 inches has a ratio of mechanical advantage of four to one.\textsuperscript{69} By extension, a treadwheel that has a “crank”—that is, the wheel—with a radius of 7 feet and a drum with a radius of 0.5 feet has an impressive mechanical advantage of fourteen to one. Therefore, given the dimensions in the example above, the treadwheel is three and a half times more efficient mechanically than the windlass.

With limestone weighing about 165 pounds per cubic foot and masonry mortar about 116 pounds per cubic foot,\textsuperscript{70} the labor-saving advantages of hoisting machinery are obvious. Human effort is greatly reduced. Prior to the development of this machinery, materials were carried aloft by laborers with hods, panniers, or handbarrows, climbing up planks, ladders, or hurdles. The weight limits to hand-carried ashlar were determined both by the workers’ strength and by the stability of scaffolding and hurdles. In addition, the smaller blocks—necessitated by hand carriage—also increased cutting

\textsuperscript{67}Vienna, Nationalbibliothek, Cod. 2759, fol. 10r.
\textsuperscript{68}C. E. Pearce, \textit{Principles of Mechanism} (New York, 1934), p. 94.
\textsuperscript{69}Ibid.
costs in the quarry. For a given weight of stone, smaller blocks have a greater area of cut surface than an equal weight of larger blocks.

The treadwheel crane's efficiency as a hoisting device is painstakingly analyzed by H. Arthur Klein, prompted by his study of Brueghel's _Tower of Babel_, painted in 1563 (figs. 12 and 13). Klein's observations are based on the treadwheels shown in this panoramic view of the construction, in which great wheels are shown operated by six men.

A healthy adult male laborer is able to deliver not much more than 0.1 horsepower, or roughly 75 watts, over an extended period of time such as several hours. In shorter bursts, however, he might produce as much as 0.3 horsepower, or 225 watts. If six workers were giving their best within a treadmill, they might deliver from 1.5 to two horsepower during a limited period of time, say a few minutes followed by a rest period.

Even if 20 percent is deducted to allow for friction in the bearings and the block-and-tackle rigging of the cranes, a net of from 1.2 to 1.6 horsepower remains. Since one horsepower is 550 foot-pounds per second, 1.2 horsepower is 660. To lift a one-ton stone slab 50 feet requires 100,000 foot-pounds of work, or energy. That amount could be supplied within about 151.5 seconds, or two and a half minutes, under the conditions described.71

Klein's analysis of the treadwheel's operation may be correct in terms of the theory of dynamics, but it is a misleading analysis of medieval building construction. He treats Brueghel as an archaeologist rather than a painter whose primary goal was the creation of a visual metaphor for mankind's hubris. Brueghel's panel is a mountainous construction modeled after the _Tower of Babel_ in the Grimani Breviary, illuminated by a Flemish painter in the early 16th century.72 In the Grimani Breviary, the Tower of Babel sits in the background of a lively construction scene that includes quarrying, carving stone, and carting materials toward the tower and up the spiraling ramp on its exterior. The construction zone is topped by a treadwheel crane. Other materials are unloaded from ships near the construction site by a double-wheeled treadwheel crane. Because of the illumination's small size and the placement of the treadwheels in the composition's background, details of the human locomotion are not visible.

72Venice, Biblioteca Marciana, fol. 206r, reproduced in DuColombier (n. 1 above), pl. 21.
Fig. 12.—This panoramic spectacle of the Tower of Babel uses building construction as a metaphor for mankind's hubris. The heavy double treadwheels described are more commonly found at seaports. The 1563 painting is by Pieter Brueghel. (Courtesy of the Kunsthistorisches Museum, Vienna.)
Brueghel has moved enormous dockside treadwheel cranes onto his version of construction of the Tower of Babel, peopled them with an inefficient number of workers, and assumed load sizes that are not relevant to medieval building. With a team of six men, the mechanical efficiency of the machine declines, because the men in the back detract somewhat from the efforts of the men in the front. If these men are walking abreast, then Klein is still using them inefficiently. Assuming the fourteen-to-one ratio discussed above, each man is
raising only about 28 pounds. Finally, few, if any, medieval cathedrals contain blocks of 1 ton.

Fortunately, we do not have to rely solely on a theoretical analysis to prove the efficiency of medieval treadwheels, because until recently the medieval treadwheel at Canterbury Cathedral was still being used. When the Bell Harry Tower was releaded during the 1970s, Keith Entwistle, a laborer at Canterbury, daily walked within the wheel, raising poles for the scaffolding, timber, and sheets of lead. Although he weighed only about 155 pounds, he claimed that the treadwheel, propelled by one or two men, could raise 8 hundredweight (British) or about 900 pounds. When the load proved too heavy for him to raise smoothly, a second man would hop into the wheel with him and bring up the load. However, Entwistle emphasized the awkwardness of walking next to a partner in the wheel. Each man could only balance himself by holding one set of struts and was constantly jostled by the other.

Standing by the trapdoor, another worker directed the operation and, if necessary, applied the brake. This brake was usually a simple wedge, jammed between the wheel and the flooring. None of the surviving English machines has a ratchet to prevent the load from running backward. Thus, a carefully orchestrated team effort was required to move the objects aloft smoothly and safely. Problems did occur. In one minor incident at the Canterbury treadwheel, Entwistle put his foot through a rotted plank on the treadway. A more serious accident involved a worker who was walking in the wheel when a load got out of control. He rode the wheel until he tumbled from its apex and broke his ankle. This incident prompted the British Health and Safety Commission to declare the wheel unsafe and forbid its further use. Entwistle greatly regretted this because cranking the winch that replaced the medieval treadwheel was backbreaking work.

Given the positive attitude toward the medieval treadwheel expressed by someone who actually used it, we should examine the negative associations that color our perceptions. For us, the subtext of "treadwheel" and "treadmill" is a monotonous and seemingly endless exertion of energy, expended just to remain in one place. The treadwheel has become an analogy for repetitive and unrewarding work frequently associated with assembly-line production or bureaucratic paper pushing.

\(^{74}\)Hewett (n. 35 above), p. 67.
\(^{75}\)Interviews with Entwistle and emphasized, as well, by Landels (n. 4 above), p. 93.
The historical origins for this attitude stem from the treadwheel's role in Britain's prison system during the 19th century. When introduced in 1817 at Brixton prison near London, the treadwheel was designed to reduce the "idle loitering" and "louting" in the prison yards by working teams of men on giant treadwheels. Coldbath Fields prison had six wheels, each of which could employ twenty-four men at a time. Each man stood in a compartment about 2 feet wide and walked up steps placed 8 inches apart on the outside of the wheel. Prison wardens soon realized the harshness of such exercise, which was exacerbated by the prison diet. Consequently, men were restricted to fifteen- to twenty-minute periods at the wheel. The physical harshness of the exercise was compounded by its futility. The treadwheel at Coldbath Fields was linked to a large regulator or fan outside the building, which was turned by the men's actions. "Grinding the wind" was regarded even by some contemporary penal authorities as a pointless exercise, "an employment which is enough to make him [the prisoner] avoid all labour to the end of his days." The treadwheel at Holloway prison differed only in that the work was not completely futile. The treadwheel pumped water for the entire prison from a deep well.

The work associated with the medieval treadwheel differed from these penal treadwheels in several important ways. Structurally, the medieval wheel was relatively small, with a circumference of 14 to 16 feet and wide enough for only two men. The medieval drama of the wheel contrasted completely with later penal usage. The process of the medieval wheel was not a gerbil-like routine of fifteen minutes of continuous walking, followed by an equal period of rest or other work. Rather, each load raised aloft was a discrete act, a collective effort of several workers, each having a specific role. Most significantly, the medieval treadwheel was a labor-saving device that reduced the backbreaking human effort of constructing tall buildings.

In addition, since these machines were located high above the ground, one should not overlook the relative freedom that working at great heights included. This freedom is something that ironworkers, the modern equivalent of the great cathedral builders, claim as a compensation for working aloft building today's skyscrapers and bridges. The supervisor is usually at ground level, and as Keith

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77Mayhew and Binny, p. 305.

78Ibid., p. 570.
Entwistle put it with a smile; “Sometimes, we just couldn’t hear what the boss was yelling from the ground.”

Among the workers who likely applauded the reinvention of the treadwheel were the hod carriers—provided they were given work in the wheel instead of made redundant. Henry Mayhew calculated that hodmen carried a burden of about 86 pounds each trip up the scaffolding, counting 14 pounds for the hod and about 72 pounds for the load.\textsuperscript{79} These men suffered as well from their stooped posture and the constant stretching of their Achilles tendons. The physical devastation caused by this work is captured by the 19th-century builders’ adage that a hodman was considered “not fit for the ladder” after the age of forty.\textsuperscript{80}

Somewhat after its introduction on construction sites, the treadwheel was added to dockside cranes. These machines were generally larger in diameter than the ones used in building construction and frequently had double wheels connected to a single axle. The larger size was prompted by factors related to the different organizational problems being solved. First, the dockside crane was a permanent structure frequently capped by a wooden roof to prevent water damage to the machine and discomfort to the men.\textsuperscript{81} Second, the goal of dockside operations was unloading cargo and replacing it with goods piled on the quay as quickly as possible to minimize idle time for the ship.

Unloading ships was safer and cheaper done by crane than by men on gangplanks. With men inside the treadwheel, the load could be raised aloft at an even pace, and poised indefinitely, provided the crew remained in place or a brake was applied.\textsuperscript{82} Such a machine eased the transfer of heavy materials. Several dockside cranes are known from the 13th and especially the 14th centuries. Charles Czarnowsky catalogs the wheels formerly located on the docks at Strasbourg (known from a Hollar engraving), Danzig, Antwerp (from an engraving of the port dating 1515), Trier (dating 1413 and still standing), and, finally, Lüneberg (dating 1330).\textsuperscript{83} Franz Feldhaus includes a

\textsuperscript{79}Ibid., p. 305 n.
\textsuperscript{80}Ibid.
\textsuperscript{81}Mayhew has described the work of the 19th-century treadwheel cranes on the London dockside as employing from six to eight men, much wider than the medieval cranes, though smaller than the treadwheels used in the prisons. Henry Mayhew, \textit{London Labour and the London Poor} (London, 1861), 3:304.
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photograph of the Lüneberg crane, although Mark Girouard indicates that it is actually an 18th-century reconstruction based on the original. Forbes Taylor points out a house crane (still extant) used at Harwich from the 17th century until World War I and another at Nijmegen used from about 1660. Among the most famous of the dockside cranes was the giant one at the Kraanplaats at Bruges, pictured in the famous Book of Hours from Munich, and the smaller one from Nieuwpoort, which survives in the background of a 16th-century diptych by L. Blondeel.

Conclusion

Although a problematic resource, medieval illuminations have added considerably to our knowledge of the history and use of treadwheels in building construction. To the archaeological void and archival ambiguity of the term ingenium, these illuminations describe two very different kinds of early windlasses: the spoke-arm type and the crank type. Furthermore, the use of these two types of windlass seems to be distinctly regional, with the spoke-arm windlass found in Britain and northern Europe and the crank windlass in Italy. Pictorial sources also include the addition of a flywheel to an Italian crank-style windlass by 1430, considerably before its description by Leonardo da Vinci. What archaeological and pictorial sources suggest is a gradual metamorphosis of the windlass into the treadwheel with the Salisbury treadwheel providing key evidence to the transition. The final leap of invention was perhaps spurred by Vitruvius's descriptions of Roman treadwheels or a critical application of the waterwheel's structure.

Once the treadwheel emerges as a distinct magna rota, illuminations clarify its evolution from the compass-arm type to the clasp-arm type. They also provide a much earlier date for this structural improvement—1380, instead of the mid-16th century date suggested by Hewett. In addition, the use of the double treadwheel in building construction is suggested in the Bohemian illumination from about 1380 (fig. 10).

Improvements to the static crane were made by at least 1340, when another Bohemian manuscript depicts a slewing crane (fig. 11). Evidence for this advance is purely pictorial, although the lack of pivoting capability was obviously a major drawback. Examples from

Mark Girouard, Cities and People (New Haven, Conn., 1985), p. 60.
Taylor, p. 204.
Munich, Staatsbibliothek, cod. lat. 23638, fol. 11v.
Girouard, pp. 61–62.
the late 15th century suggest a more elaborate rotation, as in Jean Fouquet's Temple of Solomon and Jean Colombe's Building of Troy.89

Using illuminations to analyze the placement of treadwheels on buildings under construction is problematic. Treadwheels are generally shown on the building's exterior—located either on the ground, cantilevered at midpoint, or mounted at the construction zone. Artists may have placed treadwheels there because the actual location would have necessitated an interior view of the building. That would not have worked pictorially for the generally panoramic description favored by most medieval artists.

However, of the 339 images analyzed for this study, only twelve show windlasses and twenty-nine include treadwheels. So perhaps treadwheels were located inside buildings under construction. Artists may have alluded to windlasses and treadwheels located inside the structure through the numerous cranes of various configuration sprouting from buildings under construction. Pictorially, these cranes function as an abbreviated symbol of construction.

The origins and diffusion of the treadwheel can also be traced through manuscript illuminations. While the first example appears in French archives and a French manuscript (fig. 9), the second pictorial reference comes from a crusader manuscript done in a Syrian atelier between 1275 and 1291.90 Its model, however, was a Parisian manuscript—now lost.

French and German artists more readily included the treadwheel than any other regional group. Possible reasons for this are numerous. French and German builders were the most structurally daring of Europe, and the vertical soar of their cathedrals was greatly aided by hoisting machines to raise materials aloft. Artists of these regions noticed these machines and included them in their paintings. Paradoxically, Italy, which nurtured such gifted engineer-artists as Brunelleschi, Francesco di Giorgio, Taccola, and Leonardo da Vinci, produced artists who rarely included hoisting machines in their scenes of building construction. Italian artists preferred describing males laboring under stress with accentuated musculature and dramatic postures.

89Details of Fouquet's work can be seen in Harvey (n. 1 above), figs. 15 and 21. A full illustration can be found in Paul Durrieu, Les Antiquités judaïques et le peintre Jean Fouquet (Paris, 1908), pl. viii. The manuscript itself can be found in Paris, Bibliothèque nationale, MS fr. 247, fol. 163. The work attributed to Jean Colombe is illustrated in DuColombier (n. 1 above) and in an isolated folio, Berlin, Kupferstichkabinett 4645.

Our view of technology is conditioned by the era of robotics and by the attitude that replacing human labor with machine labor is generally cheaper and, therefore, better business. Reducing labor costs is a major component in making businesses competitive. In contrast to our modern perspective, the archives and these paintings suggest that contracts for cathedrals and castles did not necessarily go to the lowest bidder. Labor-saving machines like treadwheels and wheelbarrows continue to coexist with more labor-intensive carriers like hods and handbarrows. The inclusion of both in medieval manuscript illuminations could be explained as an example of artists simply adding machines as new motifs to their repertoire of traditional building images. Nevertheless, the archives suggest that old and new machinery existed together on construction sites as well. This curious lack of interest in labor-saving machines implies that the economics of building construction were managed inefficiently—at least, from a modern point of view. Perhaps some of these large royal construction projects, having tens of handbarrows to every windlass or wheelbarrow, were regarded as a form of social welfare.

Scholarly attention has focused enthusiastically on the technological revolution of the Middle Ages. This is a look at one aspect of it, the degree to which the changes in building-construction techniques were noted by a visually literate portion of society and the frequency with which these artists incorporated two of the most noticeable new machines into their pictorial vocabulary. Again, for the 20th-century mentality—if it’s new, it’s better—the relative lack of interest these artists demonstrate is appalling. Of 339 images, chosen from a broad cross section of manuscripts and texts, only twenty-nine have treadwheels or windlasses, and eighteen have wheelbarrows. Nor were building machines the only aspect of this technological revolution that was picked up slowly by artists. The windmill, for which firm archival evidence exists from the 12th century, does not appear in manuscript illumination until 1270 in an English manuscript, aptly named the Windmill Psalter. We must conclude that tradition weighed heavily on the artists.

The perception of invention, like the inventions themselves, required a certain climate, coupled with a few perceptive and skilled individuals who could describe these inventions in painting. Describ-

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92 Lynn White’s enormous volume of work is, of course, the best known.

ing the work done on medieval construction sites was a difficult task for artists. Their goals were fundamentally dramatic, capturing the events of history and religion in the pictorial language of posture, gesture, costume, and setting. These construction sites were frequently just backdrops for more central dramas. Machinery and the means of construction were rarely the central point. By the 14th century, though, artists demonstrate that they have absorbed the general climate of technological advance in construction, plus other areas such as agriculture, warfare, and mining.

It is not surprising that many of the most thorough descriptions of building construction appear in manuscripts commissioned by members of the growing class of wealthy merchants and craftsmen—particularly in Flanders and England—during the 14th and 15th centuries. By their patronage of manuscripts, these merchants and craftsmen imitated the aristocracy. Through their interest in the phenomenal world, they stimulated artistic exploration of the physical world. From their own experience of work, they celebrated the pictorial expression of the labor of others.

Appendix

Extant Medieval Treadwheels and Windlasses

Belgium: Halle, O.-L.-Vrouwekerk (windlass), van Tyghem (n. 1 above), p. 188, fig. 284; Lier, St.-Gommaruskerk (windlass and capstan), van Tyghem, p. 186, fig. 280; Mechelen, St.-Rouboutskathedraal (treadwheel), van Tyghem, p. 188.

England: Beverly Minster (crossing—windlass), Hewett (n. 35 above), p. 71, fig. 58; Canterbury Cathedral (Bell Harry Tower—treadwheel), D. Ingram Hill, Canterbury Cathedral (London, 1986), pp. 80 and 85 (photograph); Durham Cathedral (northwest tower—fragmentary windlass), Hewett, p. 69, and Otto Lehmann-Brockhaus, Lateinische Schriftquellen zur Kunst in England, Wales, und Schottland, vom Jahre 901 bis zum 1307 (Munich, 1955–60), p. 391; Peterborough Cathedral (tower—windlass), Backinsell (n. 31 above), fig. 2, and Hewett, p. 69; Salisbury Cathedral (crossing tower—windlass), Backinsell, figs. 4 and 5, and Hewett, p. 70; Tewkesbury Cathedral (crossing—windlass), Backinsell, fig. 3.
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France: Auxerre, St. Etienne (crossing—treadwheel), Czarnowsky (n. 83 above), fig. 7; Beauvais, St. Pierre (north transept—treadwheel), P. Bonnet-Laborderie, Cathédrale Saint-Pierre, Beauvais (Beauvais, 1978), p. 60; Colmar, St. Martin (treadwheel), Czarnowsky, fig. 18; Locdure, Cistercian Abbey (treadwheel), I am indebted to Linda Neagley of the University of Michigan, Ann Arbor, for this reference; Mont-Saint-Michel (treadwheel), Fitchen (n. 57 above), p. 208, n. 73, notes that this treadwheel, still in use, is “reconstructed, to be sure, but unquestionably modelled on a medieval prototype”; Strasbourg, St. Thomas (treadwheel), Czarnowsky, figs. 14, 15, 16, 20, 21; Thann (Alsace), St. Thiebaut (treadwheel), Czarnowsky, fig. 17.

Germany: Hagenow, St. Georges (windlass), Czarnowsky, fig. 19; Schwäbisch Gmünd, Heiligkreuzkirche (treadwheel).

Sweden: Stockholm, Storkyrkan (treadwheel): Svante Lindqvist of the Royal Institute of Technology, Stockholm, designed a project in which the treadwheel of this cathedral was duplicated by students taking a course in the history of technology. His findings were presented at the International Congress of History of Science at the University of California, Berkeley, in August 1985.