THE CAMBRIDGE WORLD HISTORY

VOLUME V
EXPANDING WEBS OF EXCHANGE AND CONFLICT, 500 CE–1500 CE

EDITED BY
BENJAMIN Z. KEDAR AND
MERRY E. WIESNER-HANKS

THE CAMBRIDGE WORLD HISTORY

*

VOLUME V

Expanding Webs of Exchange and Conflict, 500 CE–1500 CE

*

Edited by

BENJAMIN Z. KEDAR
Hebrew University of Jerusalem
and
MERRY E. WIESNER-HANKS
University of Wisconsin-Milwaukee

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9780521190749

First published 2015

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall

A catalogue record for this publication is available from the British Library

ISBN 978-0-521-19074-9 Hardback

In honor and memory of Shmuel N. Eisenstadt (1923–2010) and Sabine MacCormack (1941–2012)

Contents

List of figures xii
List of maps xiv
List of table xv
List of contributors xvi
Preface xix

1 · Introduction 1
BENJAMIN Z. KEDAR AND MERRY E. WIESNER-HANKS

PART I:
GLOBAL DEVELOPMENTS

2 · Humans and the environment: tension and co-evolution 43
JOACHIM RADKAU

3 · Women, family, gender, and sexuality 70
SUSAN MOSHER STUARD

4 · Society: hierarchy and solidarity 94
SUSAN REYNOLDS

5 · Educational institutions 116
LINDA WALTON

6 · Warfare 145
CLIFFORD J. ROGERS

PART II:
EURASIAN COMMONALITIES

7 · Courtly cultures: western Europe, Byzantium, the Islamic world, India, China, and Japan 179
PATRICK J. GEARY, DAUD ALI, PAUL S. ATKINS, MICHAEL COOPERSON, RITA COSTA GOMES, PAUL DUTTON, GERT MELVILLE, CLAUDIA RAPP, KARL-HEINZ SPIEẞ, STEPHEN WEST AND PAULINE YU

8 · The age of trans-regional reorientations: cultural crystallization and transformation in the tenth to thirteenth centuries 206
BJÖRN WITTROCK

PART III:
GROWING INTERACTIONS

9 · Trade and commerce across Afro-Eurasia 233
RICHARD SMITH

10 · European and Mediterranean trade networks 257
MICHEL BALARD

11 · Trading partners across the Indian Ocean: the making of maritime communities 287
HIMANSHU PRABHA RAY

12 · Technology and innovation within expanding webs of exchange 309
DAGMAR SCHÄFER AND MARCUS POPPLOW

13 · The transmission of science and philosophy 339
CHARLES BURNETT

14 · Pastoral nomadic migrations and conquests 359
ANATOLY M. KHAZANOV

PART IV:
EXPANDING RELIGIOUS SYSTEMS

15 · The centrality of Islamic civilization 385
MICHAEL COOK

16 · Christendom's regional systems 415
MIRI RUBIN

17 · The spread of Buddhism 447
TANSEN SEN

PART V:
STATE FORMATIONS

18 · State formation and empire building 483
JOHANN P. ARNASON

19 · State formation in China from the Sui through the Song dynasties 513
RICHARD VON GLAHN

20 · The Mongol Empire and inter-civilizational exchange 534
MICHAL BIRAN

21 · Byzantium 559
JEAN-CLAUDE CHEYNET

22 · Early polities of the Western Sudan 586
DAVID C. CONRAD

23 · Mesoamerican state formation in the Postclassic period 610
MICHAEL E. SMITH

24 · State and religion in the Inca Empire 638
SABINE MACCORMACK

25 · "Proto-globalization" and "Proto-glocalizations" in the Middle Millennium 665
DIEGO OLSTEIN

Index 685

Figures

1.1 The Honköji copy of the 1402 Korean Kangnido map of the world / Pictures From History / Bridgeman Images 3
1.2 Al-Idrīsī's world map, twelfth century (Bodleian Library, Ms. Pococke 375, fols. 3v–4a) 6
1.3 Pietro Vesconte's world map, *c.* 1321 (Bodleian Library, Ms. Tanner 190, fols. 203v–204r) 8
1.4 Giovanni Leardo's world map, 1448 (DEA Picture Library / Getty Images) 9
3.1 Prince Genji visiting his wife, from Genji Monogatari (The Tale of Genji) (The Art Archive / Alamy) 76
3.2 German family spinning, sixteenth century (Mary Evans Picture Library / Alamy) 78
5.1 Ruins of Buddhist university at Nalanda (photograph by Tansen Sen) 123
5.2 Elite boys enter a *calmecac*, from the Florentine Codex by Bernardino de Sahagun, *c.* 1540–85 (Ms palat. 218–220 Book IX. Biblioteca Medicea-Laurenziana, Florence, Italy / Bridgeman Images) 139
6.1 Bulghar warrior on a gold jug (or pitcher) from the Treasure of Nagyszentmiklós (Erich Lessing Culture & Fine Arts Archive) 148
6.2 Mongols and Japanese fight, in a scene from the Mōko Shūrai Ekotoba, a Japanese handscroll made between 1275 and 1293. /Pictures From History/ Bridgeman Images 168
6.3 The Battle of Avray in 1364, Master of Mary of Burgundy (*fl.* 1469–83) (Ms 659 f.271 r. Collection of the Earl of Leicester, Holkham Hall, Norfolk / Bridgeman Images) 173
7.1 Mahmud ibn Sebüktegin receives a robe of honour from the Caliph al-Qādir billāh in 1000, miniature from the '*Jāmi' al-tawārīkh*' of Rashīd al-Dīn, *c.* 1307 (vellum) (Ms Or 20 f.121r. Edinburgh University Library, Scotland. With kind permission of the University of Edinburgh / Bridgeman Images) 187
9.1 Bayon temple in Angkor, market scene (photograph by Benjamin Kedar) 240
12.1 Design for a Chinese water clock, by Su Song, 1088 CE (School of African and Oriental Studies, London, UK / Bridgeman Images) 325
12.2 Geometrical figures for construction, arches and man measuring the height of a tower (facsimile copy, pen & ink on paper), Villard de Honnecourt (*fl.* 1190–1235) (Ms.Fr.19093 fol.20v. Bibliothèque Nationale, Paris, France / Giraudon / Bridgeman Images) 327

15.1 Islamic coins (photographs by Michael Cook) 397
16.1 Ivory plaque with the Adoration of the Magi, Early Byzantine, early sixth century (©The Trustees of the British Museum. All rights reserved) 423
16.2 The Holy Family, Joos van Cleve, *c.* 1485–1540/41, Antwerp (Metropolitan Museum of Art / © SCALA) 425
17.1 Buddhist figures, Longmen Caves, Henan Province (Private Collection © Leemage / Bridgeman Images) 456
17.2 Pensive Bodhisattva, mid seventh century, Korea (Metropolitan Museum of Art / © SCALA) 463
20.1 The Birth of the Prophet Muhammad, miniature from the '*Jāmiʿ al-tawārīkh*' of Rashīd al-Dīn, *c.* 1307 (vellum) (Ms Or 20 f.42r. Edinburgh University Library, Scotland. With kind permission of the University of Edinburgh / Bridgeman Images) 544
22.1 Illustration of Mansa Musa in detail from the Catalan Atlas, 1375 (vellum), Cresques Abraham (1325–87) (Bibliothèque Nationale, Paris, France / Bridgeman Images) 601
23.1 Chronological outline for Postclassic Mesoamerica 617
23.2 Trends in Postclassic polities 629
24.1 Sacsayhuaman: Inca Ruins (Aivar Mikko / Alamy) 659

Contributors

Daud Ali, University of Pennsylvania
Johann P. Arnason, La Trobe University, Melbourne
Paul S. Atkins, University of Washington
Michel Balard, University of Paris / Panthéon-Sorbonne
Michal Biran, Hebrew University of Jerusalem
Charles Burnett, Warburg Institute, London
Jean-Claude Cheynet, University of Paris-Sorbonne
David C. Conrad, State University of New York at Oswego
Michael Cook, Princeton University
Michael Cooperson, University of California, Los Angeles
Rita Costa Gomes, Towson University, Baltimore
Paul Dutton, Simon Fraser University, Burnaby, British Columbia
Patrick J. Geary, Institute for Advanced Study, Princeton
Benjamin Z. Kedar, Hebrew University of Jerusalem
Anatoly M. Khazanov, University of Wisconsin-Madison
Sabine MacCormack, Notre Dame University
Gert Melville, Technical University of Dresden
Diego Olstein, University of Pittsburgh
Marcus Popplow, Technical University of Berlin
Joachim Radkau, University of Bielefeld
Claudia Rapp, University of Vienna
Himanshu Prabha Ray, National Monuments Authority, New Delhi
Susan Reynolds, University of London
Clifford J. Rogers, United States Military Academy, West Point
Miri Rubin, Queen Mary College, University of London
Dagmar Schäfer, University of Manchester
Tansen Sen, Baruch College, City University of New York
Michael E. Smith, Arizona State University
Richard Smith, Ferrum College, Virginia
Karl-Heinz Spieß, University of Greifswald
Susan Mosher Stuard, Haverford College, Pennsylvania
Richard von Glahn, University of California, Los Angeles
Linda Walton, Portland State University

Stephen West, Arizona State University
Merry E. Wiesner-Hanks, University of Wisconsin-Milwaukee
Björn Wittrock, Uppsala University
Pauline Yu, American Council of Learned Societies

12

Technology and innovation within expanding webs of exchange

DAGMAR SCHÄFER AND MARCUS POPPLOW

During the Middle Millennium, technology and innovation contributed to the rise and fall of cultures, societies, and empires, in the form of military strength and agricultural development, as well as by the reification of cultural, ritual, and social practice. They often appear as mediating forces between agents, societies, systems, and environments, although contemporaries only infrequently identify them as such explicitly.

Studies with a global perspective on technology and social change during the Middle Millennium are actually quite rare. Historians of this era generally explore narratives of a culture or region.[1] Researchers assert that technologies emerged as phenomena that were recognized and expressed quite heterogeneously across time and space. Innovation was a constantly changing variable, defined and circumscribed by changing desires and needs, and by human interactions with the physical environment. Few general conclusions have therefore been drawn from research on technology in global perspective during the Middle Millennium, while substantial questions of methodology remain.

1 For such comprehensive studies on particular cultures, see Joseph Needham, *Science and Civilisation in China*, vols. I–VII (Cambridge University Press, 1954–2008); Francesca Bray, *Technology and Society in Ming China (1368–1644)* (American Historical Association: Washington DC, 1997); Donald Hill, *Medieval Islamic Technology. From Philo to Al-Jazari – From Alexandria to Diyar Bakr* (Aldershot: Ashgate, 1998); Abdhur Rahman, *History of Indian Science, Technology and Culture AD 1000–1800* (Oxford University Press, 1998); Frances Gies and Joseph Gies, *Cathedral, Forge, and Waterwheel. Technology and Invention in the Middle Ages* (New York: HarperCollins, 1994); Marcus Popplow, *Technik im Mittelalter* (Munich: C. H. Beck, 2010); for studies covering several cultures see Pamela O. Long, *Technology and Society in the Medieval Centuries: Byzantium, Islam, and the West, 500–1300* (Washington DC: American Historical Association, Society for the History of Technology, 2003); James E. McClellan III and Harold Dorn, *Science and Technology in World History. An Introduction* (Baltimore: Johns Hopkins University Press, 2006): 97–201; Thomas Glick, Steven J. Livesey and Faith Wallis, *Medieval Science, Technology and Medicine. An Encyclopedia* (New York, London: Routledge, 2005).

This chapter addresses some major issues and methodological concerns emerging from the socio-historical view of technology and innovation. It tackles some of the 'highlights' of technical ingenuity in different world regions during the Middle Millennium, using identifications such as 'Chinese', 'Indian', 'Islamic' or 'European' to reflect approximations for regionally anchored politically and socially influential groups representing distinct ideals and traditions. The chapter then discusses constitutive factors of cultural frameworks of innovation evident on the global stage, transmission processes, and the relation between ruling powers and technology.

Scholarship on technology

Historical studies of technologies, exchange, and innovation in the Middle Millennium have largely focused on the Eurasian continent, where empires, cultures, and individuals created oscillating spheres of influence and varying contact zones. Africa, the Southeast Asian archipelagos or the peninsulas of northern Europe often function as periphery, while the Americas and Australia are largely ignored. The medieval historian Lynn White Jr substantially shaped the methodology of the history of technology in the 1960s–70s, markedly setting Europe as the framework for any comparative global account.[2] While achievements of Islamic cultures or Chinese traditions have sometimes been foregrounded, they tend to remain the comparative 'other'.

In the post-White era, historians, archaeologists, linguists, and anthropologists have emphasized the European Middle Ages as a period of clear technological development, presaging modern innovative creativity through the production of numerous innovative technologies and inventions. On this basis, the economic historian Joel Mokyr argues that creative medieval European technology forms an integral part of the larger historical narrative of modern economic progress in the Western world.[3] David Landes' account

2 Lynn White, Jr, *Medieval Technology and Social Change* (Oxford University Press, 1962); Lynn White, Jr, *Medieval Religion and Technology* (Berkeley: University of California Press, 1978); For recent critics of White's theses see B. S. Hall, 'Lynn White's Medieval Technology and Social Change after Thirty Years', in Robert Fox (ed.), *Technological Change: Methods and Themes in the History of Technology* (Amsterdam: Harwood Academic, 1996): 85–101; Alex Roland, 'Once More into the Stirrups: Lynn White, Jr, Medieval Technology and Social Change', *Technology and Culture* 44 (2003): 574–85. For White's Eurocentrism see James M. Blaut, *Eight Eurocentric Historians* (New York, London: The Guilford Press, 2000): 31–44.

3 Joel Mokyr, *The Lever of Riches: Technological Creativity and Economic Progress* (Oxford University Press, 1990): 31–56 and 201–8; see also Avner Greif, *Institutions and the Path to the Modern Economy: Lessons from Medieval Trade* (Cambridge University Press, 2006).

of Western cultural supremacy and hegemony during the last millennium also traces modern economic disparities and political power regimes to the Middle Ages.[4] While the works of Landes and Mokyr highlight continuity within European developments, others assert that Europe only began to show distinctive signs of divergence from other world regions after 1500.[5] Arnold Pacey emphasizes that Asian regions surpassed European technological developments for long periods up until 1800.[6]

Global accounts of medieval technology often apply a phenomenological approach, circling around a device such as a plough, an artefact such as paper or a resource such as water. Studies list technological achievements in fields such as mechanical engineering, textile technology, or methods of communication, and compare them in various regions in terms of output and impact, size, production processes and period of origin. Agriculture, architecture and water regulation, military weaponry, textiles, and iron production are employed in unifying approaches to 'technology', and are then compared in terms of features and scales. Many studies are oriented towards large-scale and 'industrial' production schemes, and relate to the employment of tools and machines, with development measured in terms of spectacular engineering achievements. In contrast, everyday practices such as the production of shoes, or the technologies of heating, cooking, sewing, or tanning are depicted as local, basic and interchangeable with negligible global impact. Knowledge flows in such commonplace practices are difficult to reconstruct, since they took place below the radar of state or elite written recognition, but a more thorough integration of archaeological research might help to overcome such a skewed perspective in the future.[7]

The global view has revealed that many of the elements attributed to European industrialization and 'modern' global structural developments emerged in other regions first. For example, the Chinese Song (960–1279)

Michael Mitterauer, *Warum Europa? Mittelalterliche Grundlagen eines Sonderwegs* (Munich: C. H. Beck, 2003) compares particularities of medieval European developments to other world regions, including those on the technological level.

4 David Landes, *The Wealth and Poverty of Nations: Why Some are so Rich and Some so Poor* (New York: W.W. Norton, 1999) see esp. Chapter 4.

5 K. N. Chaudhuri, *Asia before Europe: Economy and Civilisation of the Indian Ocean from the Rise of Islam to 1750* (Cambridge University Press, 1990): 297–337.

6 Arnold Pacey, *Technology in World Civilization: A Thousand-Year History* (Boston: The MIT Press, 1990), viii, 51.

7 For Europe, see James Graham-Campbell and Magdalena Valor (eds.), *The Archaeology of Medieval Europe, Eighth to Twelfth Centuries AD* (Aarhus University Press, 2007); Martin Carver and Jan Klápste (eds.), *The Archaeology of Medieval Europe, Twelfth to Sixteenth Centuries* (Aarhus University Press, 2011).

and Ming (1368–1644) dynasties both produced ceramics and textiles through large-scale, state-owned manufacturing that – similar to the private workshops – implemented sophisticated labour segmentation processes.[8] The porcelain city of Jingdezhen is one example of a regional manufacturing centre with good global trade links since at least the thirteenth century.[9] Manufacturers and factories of a comparable size or complexity did not appear in European countries such as Britain until the eighteenth century. A global view of technology thus reveals the nonlinear character of technological change.

Historians of the Asian Middle Millennium who approach technology and innovation often highlight use and consumption, since state and elite interests and trade are the most visible historical interfaces of technological knowledge diffusion. For example, during the Tang dynasty (618–907), elite interests in horses, spices and herbs, and products made by foreign goldsmiths fostered trade and cultural exchanges.[10] In contrast, Song literati attempting to strengthen their 'culture' (*wen*) invested in refined local styles. Researchers have shown that aside from changing taste, patterns of consumption and use were affected by the availability of materials, and the ways in which people learnt to process them. For example, as access to silver from Yunnan improved and trade with Bengal increased during the late Tang, Chinese elites began to favour silver ware over ceramics.[11] Silver workshops flourished into the Song period, while at the same time potters developed kiln technologies and learnt to fire porcelaneous wares at a higher temperature. The porcelain now known as 'china' emerged in northern China before production accelerated in the south.[12]

Histories of changing tastes and design demonstrate that political rulers and socially dominant elites shape technological developments, often lastingly and subtly through financial or social support rather than through overt exertion of power. In chronologies of consumption, moral, political, and social issues converge with economic concerns or ideas about the value of

8 For a discussion of the idea of modular design, see Lothar Ledderose, *Ten Thousand Things: Module and Mass Production in Chinese Art* (Princeton University Press, 2001).

9 Anne Gerritsen, 'Ceramics for Local and Global Markets: Jingdezhen's Agora of Technologies', in Dagmar Schäfer (ed.), *Cultures of Knowledge: Technology in Chinese History* (Leiden: Brill, 2012): 161–84.

10 Edward H. Schafer, *The Golden Peaches of Samarkand: A Study of T'ang Exotics* (Berkeley and Los Angeles: University of California Press, 1985).

11 Yang Bin, 'Horses, Silver, and Cowries: Yunnan in Global Perspective', *Journal of World History* 15.3 (2004): 281–322.

12 Nigel Wood, *Chinese Glazes: Their Origins, Chemistry and Recreation* (Philadelphia: University of Pennsylvania Press, 1999).

materials, and the larger context is revealed. In contrast, historians of medieval technology in Europe have paid more attention to production, showcasing the impact of labour and materials on changing technological repositories.

Change and continuity

European Renaissance humanists established the idea that technological inventions stood at the heart of periodic developmental leaps. For them, the European invention of gunpowder, printing, the compass and subsequent voyages of discovery (and colonization) impelled a new age of human endeavour which, in stark contrast to the localized, 'dark', Middle Ages, operated at a global scale. The modern historiography of China has identified a climax during the Song dynasty, when scholars increasingly discussed and recorded earlier and contemporary technological innovations. Illustrated catalogues or state documents account for hydraulic, agricultural, astronomical, and military change: textile manufacture, printing, dyeing, transportation, and building technologies were modified.

Recent historical research has emphasized that technological development is rarely sudden or unprecedented, but evolutionary in nature. 'If technology', as George Basalla commented, 'is to evolve, then novelty must appear in the midst of the continuous', which suggests that old technologies should be studied in as much depth as more spectacular innovations.[13] Hydraulic engineering, astronomy, and medicine continued from the Koryŏ (918–1392) to the Chosŏn dynasties (1392–1897) in what is now Korea, with no sudden ruptures.[14] Starting from such a perspective, innovation is shown to be transient within long-term processes of knowledge accumulation, where the new can only take root if it is founded on a fading old technology. Maintenance and repair of existing technologies led to as many innovations as did unique moments of ingenuity.

In fact, numerous studies have demonstrated that technologies emerging after 500 were strongly related to pre-500 experiences, and achievements of the early modern period rooted in developments of the Middle Millennium. Heavy ploughs and mills, for example, had evolved in Europe slowly and

13 George Basalla, *The Evolution of Technology* (Cambridge University Press, 1988), viii.

14 See John B. Duncan, *The Origins of the Chosŏn Dynasty* (University of Washington Press, 2000): 204–28 on issues of stability, change, and reforms.

continuously since Roman antiquity.[15] Texts record the progression of milling technology in China as equally continuous pre- and post-500. The Song developed sugar crushing and woodblock printing based on knowledge that had come to their region earlier from South Asia.

Discontinuities evolved in the diversification of basic grain-mill technologies, which were also employed to drive bellows of iron furnaces and run water-lifting devices. Researchers intensively debate the extent to which these machines were in fact employed for such purposes in medieval Europe or Asia. Earlier claims that their employment allows us to speak of an 'industrial revolution' in the European Middle Ages have proven to be exaggerated.[16] In England, for instance, 10,000 or so mills existed in 1300, but these provided only 6 per cent of all required kinetic energy, while animals supplied 75 per cent and the rest came from humans.[17]

In China, mills developed differently not because of different attitudes towards mechanical technology, but simply because the most populated southern regions relied mainly on rice that does not require milling. Conversely, during the eleventh century, Song scholars described large and complex machines for silk-reeling and weaving, and water-driven bellows through which blast furnaces could reach temperatures high enough to allow the direct casting of iron products instead of having first to produce wrought iron.[18] In addition, the ways in which the same device was used were open to change: Wang Zhuo (1081–1161) notes that Chinese monasteries and farmers had already used an edge runner for oil processing before they applied it to the crushing of sugar cane.[19]

Such examples demonstrate that any era's attitude towards innovation and technology is the result of complex social and cultural processes. Evidently, people identified technologies as much from the political and social power regimes within which they were embedded as through actual use. As a general rule, contemporary commentators seem to have identified

15 John Langdon, *Mills in the Medieval Economy: England 1300–1540* (Oxford University Press, 2004); Adam Lucas, *Wind, Water, Work: Ancient and Medieval Milling Technology* (Leiden: Brill, 2006).

16 Jean Gimpel, *La Révolution industrielle du Moyen Age* (Paris: Éditions du Seuil, 1975).

17 John Langdon, *Horses, Oxen, and Technological Innovation: The Use of Draught Animals in English Farming from 1066 to 1500* (Cambridge University Press, 1986): 117–18.

18 Donald B. Wagner, *The Traditional Chinese Iron Industry and Its Modern Fate* (Richmond: Curzon Press, 1997): 12–14.

19 Wang Zhuo (twelfth century), *Tang shuang pu* [Tract on sugar frosting, +1145], Wenyuan ge siku quanshu edition-online database, preface, 1a; see also Sucheta Mazumdar, *Sugar and Society in China: Peasants, Technology, and the World Market* (Boston: Harvard Yenching Institute, 1998): 172–6.

technological innovation as an agent of change in the military field more than any other. In medieval Europe, for example, the crossbow and longbow affected combat strategies. Clearly many factors had to come together to make such a singular technical innovation effective. Training as well as heavy financial investment paved the way for new types of military equipment such as the gunpowder weapons that were soon used across Eurasia.[20] Artefacts like the heavy plough, the water mill, and the horse-collar could only boost agrarian change in medieval Europe because they were combined with three-field crop rotation, the introduction of specific grains (especially rye and oats) and because they could be accommodated in the yearly labour cycle of peasants.[21] Technologies were interdependent forces that had to be developed in correlation to allow for a leap. Contemporary commentators rarely took notice of such complex implications, however, and instead discussed the relevance of innovations mainly within their own region and remit.

A deliberate balance of the old and new stabilized cultures during times of peace, whereas war, disease, and environmental catastrophe often shed a new light on everyday technologies. Both in war and peace, technological knowledge got lost, resurfaced or was transformed. The sophisticated managerial knowledge in architecture and irrigation of the Khmer Empire of Southeast Asia disappeared when the fourteenth century brought periods of war. After substantial growth in the High Middle Ages, central European mining regions collapsed in the wake of the Black Death (*c.* 1347–51). In the fifteenth century territorial rulers took over mining administration and new techniques enabled workers to extract silver from deposits previously considered not worthy of exploitation. With the collapse of the Roman Empire, long-distance infrastructure deteriorated, but competitive medieval rulers continued to use streets and aqueducts locally.

New sociopolitical structures often spurred technological changes. In China, women who had raised sericulture to new economic heights in household production during the Song dynasty were de-skilled and pushed back into the private sphere as the Ming dynasty built up its network of state-owned weaving and dyeing workshops.[22] Political shifts stimulated new

20 Peter Lorge, 'Development and Spread of Firearms in Medieval and Early Modern Eurasia', *History Compass* 9,10 (2011): 818–26.

21 Grenville Astill and John Langdon (eds.), *Medieval Farming and Technology: The Impact of Agricultural Change in Northwest Europe*, Technology and Change in History, vol. 1 (Leiden: Brill, 1997).

22 Francesca Bray, *Technology and Gender: Fabrics of Power in Late Imperial China* (Berkeley and Los Angeles: University of California Press, 1997): 248.

methods of defence, ideas of communication, and routes of contact that went as far as Central Asia.[23] Northern tribes compelled Song dynastic inhabitants during the twelfth century to migrate south. They adapted plants and animals from the north and cultivated new plants. Exchanges from completely different environments could have a broad effect, stimulating cultures to consider new agricultural schemes and new technological equipment, which then in turn spurred new infrastructures and new political and social forms. Contemporary commentators recognized such complex implications, drawing with great mastery on local sources and means.

In many cases, attention turned to what we now identify as technology when cultures struggled to find methods of recruiting larger amounts of energy, and worked to expand resources of food and materials for use in producing the arts and crafts.[24] Population density, urbanization and the accrual of artisanal processes increased the demand for energy, food, water and shelter, and limitations had to be overcome.[25] While mechanization, slowly increasing during the Middle Ages, indeed powered European industrialization in the eighteenth and nineteenth century, Chinese and Indian textile production and agricultural processes advanced, based on intensive labour schemes, small-scale family businesses, and diversification. In the cotton industry that prospered over long periods on the Indian subcontinent, productivity relied on a multitude of minor organizational and managerial innovations, in contrast to modern industrialization that depended on the mechanization of labour.[26]

Workshop owners and state officials innovated sectors with a concern about the availability of materials, funds, and skills. Actors were concerned about simple and resource-saving solutions and rarely fancied new equipment or complex machinery in their developmental strategies. In the Near East, for example, *qanats*, i.e. underground channels, irrigated fields over several kilometres efficiently without additional pumping, functioning reliably through an inbuilt downhill gradient.[27]

23 Kenneth Chase, *Firearms: A Global History to 1700* (Cambridge University Press, 2003).

24 Elizabeth B. Smith and Michael Wolfe (eds.), *Technology and Resource-Use in Medieval Europe: Cathedrals, Mills, and Mines* (Aldershot: Ashgate, 2004); Mark Elvin, *The Retreat of the Elephants: An Environmental History of China* (New Haven: Yale University Press, 2004).

25 Paolo Malanima, *Pre-modern European Economy: One Thousand Years (10th–19th Centuries)* (Leiden: Brill 2009): 49–94.

26 Giorgio Riello and Prasannan Parthasarathi (eds.), *The Spinning World: A Global History of Cotton Textiles* (Oxford University Press, 2009): 360–6.

27 Edmund Burke III, 'Islam at the Center: Technological Complexes and the Roots of Modernity', *Journal of World History* 20,2 (2009): 165–86.

The motivations for innovation were manifold and hence structures also differed substantially or subtly. The Ming, for instance, standardized silk-weaving production, targeting improved quality and a diversification of patterns and textures. Consequently technical solutions in silk differed from those developed later in cotton, which in the nineteenth century emphasized quantity and standardized mass production that later spurred on mechanization.[28]

Inventions had diverse local impacts. Asian cultures employed gunpowder, printing, and compasses for centuries before these inventions reached Europe. The impact of printing on European notions of society, the state, and the self has been widely discussed. Much less recognized is that the emergence of printing also – and earlier – caused substantial social and political change in Asia and particularly in dynastic China. In the seventh century, woodblock printing emerged and prospered in the course of Buddhist proselytization. The increasing availability of printed matter was one of many factors that explains this era's changing attitudes towards religion, learning, and history, as well as social developments that came from changing attitudes towards the usage, consumption, and production of 'things (*wu*)', a Chinese category that embraced artefacts, the human, natural and supernatural, processes and materials alike. The increased application of representational media that occurred as a result of the printing press stabilized forms of technical knowledge and their transmission within statecraft and elite culture. Individual technical knowledge and specialized skills, flexibly and innovatively attuned to local or regional conditions, also found scant attention in such media-based systems of knowledge.

Some technical innovations can be directly related to political events. During the Middle Millennium, when the Khitan Liao (907–1125) and Jurchen Jin dynasty (1115–1234) forced the Han-Chinese Song dynasty into the South of Asia, Asian shipbuilders improved designs and enabled the traverse of large distances without touching land, effectively reshaping regional networks of power and trade in the 'Asian' Mediterranean.[29] European voyages of discovery in the fifteenth century appear much less dramatic when we envisage the dense networks of seafaring that connected the Islamic world with the coasts of East Asia during the eleventh and twelfth century.

28 Dagmar Schäfer, *Des Kaisers Seidene Kleider: Staatliche Seidenmanufakturen in der Ming-Zeit (1368–1644)* (Heidelberg: edition forum, 1997): 20–3.

29 Sally K. Church, 'The Colossal Ships of Zheng He: Image or Reality?' In Claudine Salmon and Roderich Ptak (eds.), *Zheng He: Images and Perceptions/Bilder und Wahrnehmungen* (Wiesbaden: Harrassowitz, 2005): 155–76.

Technologies often continued or even prospered in spite of political change. The Mongol occupation of Baghdad in 1258 did not permanently harm the highly skilled artisanal and agricultural production of this region – in fact, it remained prosperous.[30] Even though Byzantium fell in 1453, technical expertise in the region continued, enhancing the Ottoman Empire's quick rise to economic and military strength. The only cultures where technological ruptures can be seen in 1500 are the Aztec and Inca where urban planning, water management with extended irrigation systems, transportation, and mining collapsed, alongside the emergence of colonialism. As European diseases and warfare decimated the indigenous population in these regions of the world, lines of transmission were cut off.

From a birds-eye perspective, technological development during the Middle Millennium appears as a series of knowledge continuities, accumulations and losses with as many major breakthroughs as setbacks. Change occured though, so that by the sixteenth century most regions in Europe, Asia, and Africa deployed a technological apparatus remarkably different from that available around 500.

Discourses of technology

Gaps between modern and historical categories are a ubiquitous concern in the daily work of the historian. In terms of technology, the problem starts when 'attitudes' or 'ideologies' towards technology are identified for epochs in which technical objects were generally discussed separately from human technical expertise, instead of being fused in one word as they are in the modern notion of technology. Systematic research on the terminologies and discourses of pre-industrial cultures is scanty, in all world regions. Issues such as differences from modern discourses on technology have not even been discussed as a methodological problem among historians and philosophers of technology. The emic – or insiders' – perspective on discourses about innovation is thus still missing.[31] In general, scribal cultures discussed technical abilities as part of evaluations of human work or artisanal expertise in comparison with various forms of scholarship, whereas they discussed innovations and inventions as part of all sorts of material objects new to a given cultural setting. Textual recording during the Middle Millennium was

30 Denise Aigle, 'Loi mongole vs loi islamique: entre mythe et réalité', *Annales. Histoire, Sciences Sociales* 59, 5/6 (2004): 971–96.

31 Marcus Popplow, *Neu, nützlich und erfindungsreich: Die Idealisierung von Technik in der frühen Neuzeit* (Münster, New York: Waxmann, 1998).

stered in political and religious centres that shaped notions and visual presentations of technical innovation.

The relationship between actual innovations and their written documention is complex and ambiguous and none used classifications such as novation', 'invention', and 'technology' in the same sense that we underand these terms today. Instead, scholars during this period debated the pact of innovations on the human mind, the moral value of work or the nsumption of luxury goods for personal or ritual usage.[32]

Contemporaries labelled issues purposefully as new or old to situate tools, eapons and machines, large-scale technical projects, and practical and anagerial production methods within complex ethical, social, or individual oncerns. In the *Wujing zongyao* (Collection of the most important military echniques, 1044) compiled by Zeng Gongliang (998–1078), Ding Du and Yang Weide (n.d.), military tactics were endorsed with references to ancient times, classical studies, and the idealized Zhou state (fifth–seventh centuries), but the text also promoted the use of novel improved weaponry. In many places, soldiers actually engaged in war employed the latest products and most innovative technologies, while the civilian elites claimed to have superior knowledge about military principles, drawing on examples from history.

References to the past in this era both in the West and East bestowed gravitas on new ideas or products. In philosophical debates on *wuyuan*, the 'origin of things', however, Chinese scholars gave novelties a past primarily to substantiate their cultural relevance. Thus, Lü Bi in the seventeenth century explained the south-pointing chariot – a mechanism that was meant to keep pointing south whichever direction the vehicle turned – as the product of a long process of knowledge accumulation and successive subtle and substantial innovations by sages who had invented the wheel, the chariot, and the needle that again were based on earlier developments such as the bi-disc, or the spear. Lü recalled this nexus as a reminder for rightful and moral rulership in full awareness that the knowledge to construct this machine was in fact already lost.[33]

32 Themes such as the value of work were anchored in Chinese classics of the pre-imperial period like the *Li ji* (Book of Rites) or the *Kaogong ji* (Artificers Record). For Europe, see George Ovitt, *The Restoration of Perfection: Labor and Technology in Medieval Culture* (New Brunswick: Rutgers University Press, 1987).

33 Lü Bi (seventeenth century), *Shiwu chulüe* (Preliminary Summary of Things and Affairs), Siku quanshu cunmu congshu, zibu 98 (Ji'nan: Qi lu shushi chubanshe 1995 [reprint of 1637 edition]), ch. 33, 13a.

Within these debates on the 'origin of things' Chinese scholars pondered technologies and innovation as admonitions and chances for human development.[34] Imperial historiography often invoked technological innovations within a rhetoric of political and cultural dominance. Mythical figures such as the Yellow Emperor gave the civilized inhabitants of Chinese culture the implements and methods to write, print, and construct a boat or cart, while barbarians clothed themselves with furs and feathers, hunted for food or collected wild berries. Similarly, European scholars situated artisans' knowledge within general accounts of human understanding and endeavour.[35]

In China, artisanal communities informed such discourses even though historiography has highlighted the scholarly role. As a general rule, craftsmen seem to have disguised their original trade when rising into higher ranks. Artisans participated in and affected literati thought; natural philosophers brought new developments and patterns of thought into the mainstream, pondered practices and legitimized new utensils.

Technical treatises, visual representations, and scale models

Since the time of Michael Polanyi, numerous studies have indicated the role of practice and explained how 'tacit' knowledge plays an important role in the recognition of technological development and historical reflections on it. Historians of technology have not yet studied the diverse forms of artisanal expertise systematically. However, even if codification in everyday activities embedded in the diverse traditions of local family communities or regional expert communities might not be as visible as knowledge codified in writing or drawing, it doubtless secured the application and transmission of technical knowledge in various world regions. Stunning works of art produced from a wide range of materials such as metals, stone, glass, wood, and ceramics resulted from this kind of expertise. Technical instruction based on imitation rather than on specialized vocabulary and teaching institutions could cross language borders, as long as the persons involved agreed on the transmission of the expertise.

34 Martina Siebert, 'Making Technology History', in Schäfer, *Cultures of Knowledge*, 253–81, here 268.

35 Elspeth Whitney, *Paradise Restored: The Mechanical Arts from Antiquity Through the Thirteenth Century* (Transactions of the American Philosophical Society, 80[1]; Philadelphia: American Philosophical Society, 1990).

Between 500 and 1500, the makers and creators of technologies conveyed their knowledge within collaborative networks. They learned from each other and through the interchange of samples, tools or products, stabilizing their trade with ritual, social and cultural practices. Across Eurasia technical procedures were also shared through text and images, a development that formed part of the far-reaching changes in communication induced by the spread of paper from China over to the Islamic world to Europe during the Middle Millennium. Textual scripts aimed to preserve and transmit practical knowledge within a scholarly realm and elite context. To what extent texts and images also served to instruct, or were directly employed in the realization of technical projects, is still open to debate.

Across cultures, elites demonstrated a keen interest in the circulation of agricultural expertise. In China rulers pondered the documentation of farming techniques, along with spinning and weaving, as issues of societal and individual moral development in state and philosophical contexts, making agronomy a 'science of the state'.[36] In the Islamic world, officials of the Muslim caliphates equally attempted to advance new cultivation methods.[37] In Europe, by contrast, treatises on agronomy, closely linking to Roman antiquity, portrayed ideals and did not ponder practical application.

From the ninth century, scholars writing in Arabic also produced illustrated treatises on mechanical contrivances, automata, and water-lifting devices. Such works brought attention to individual expertise and ability. Rulers commissioned compilations on technical issues to substantiate their own mandate over a field of knowledge. Fifteenth-century Italian authors addressed elites in treatises on architecture and civil and military mechanical engineering. European monks described the material properties, formulae, and procedures of crafts that artisans had previously only transmitted orally and visually from father to son, or from master to disciple. In the twelfth century the German Benedictine priest known by the pseudonym 'Theophilus' provides in a work called *Diversarum artium schedula* (List of various arts) instructions for religious decorative art including painting, metalwork,

36 For a discussion of agricultural treatises and their content, see Francesca Bray, *Science and Civilisation in China, vol. vi, Part 2: Agriculture*, ed. Joseph Needham (Cambridge University Press, 1984).

37 Karl W. Butzer, 'The Islamic Traditions of Agroecology: Crosscultural Experience, Ideas and Innovations', *Cultural Geographies* (January 1994): 7–50; Michael Decker, 'Plants and Progress. Rethinking the Islamic Agricultural Revolution', *Journal of Global History* 20 (2009): 187–206.

Technologies often continued or even prospered in spite of political change. The Mongol occupation of Baghdad in 1258 did not permanently harm the highly skilled artisanal and agricultural production of this region – in fact, it remained prosperous.[30] Even though Byzantium fell in 1453, technical expertise in the region continued, enhancing the Ottoman Empire's quick rise to economic and military strength. The only cultures where technological ruptures can be seen in 1500 are the Aztec and Inca where urban planning, water management with extended irrigation systems, transportation, and mining collapsed, alongside the emergence of colonialism. As European diseases and warfare decimated the indigenous population in these regions of the world, lines of transmission were cut off.

From a birds-eye perspective, technological development during the Middle Millennium appears as a series of knowledge continuities, accumulations and losses with as many major breakthroughs as setbacks. Change occured though, so that by the sixteenth century most regions in Europe, Asia, and Africa deployed a technological apparatus remarkably different from that available around 500.

Discourses of technology

Gaps between modern and historical categories are a ubiquitous concern in the daily work of the historian. In terms of technology, the problem starts when 'attitudes' or 'ideologies' towards technology are identified for epochs in which technical objects were generally discussed separately from human technical expertise, instead of being fused in one word as they are in the modern notion of technology. Systematic research on the terminologies and discourses of pre-industrial cultures is scanty, in all world regions. Issues such as differences from modern discourses on technology have not even been discussed as a methodological problem among historians and philosophers of technology. The emic – or insiders' – perspective on discourses about innovation is thus still missing.[31] In general, scribal cultures discussed technical abilities as part of evaluations of human work or artisanal expertise in comparison with various forms of scholarship, whereas they discussed innovations and inventions as part of all sorts of material objects new to a given cultural setting. Textual recording during the Middle Millennium was

30 Denise Aigle, 'Loi mongole vs loi islamique: entre mythe et réalité', *Annales. Histoire, Sciences Sociales* 59, 5/6 (2004): 971–96.

31 Marcus Popplow, *Neu, nützlich und erfindungsreich: Die Idealisierung von Technik in der frühen Neuzeit* (Münster, New York: Waxmann, 1998).

clustered in political and religious centres that shaped notions and visual representations of technical innovation.

The relationship between actual innovations and their written documentation is complex and ambiguous and none used classifications such as 'innovation', 'invention', and 'technology' in the same sense that we understand these terms today. Instead, scholars during this period debated the impact of innovations on the human mind, the moral value of work or the consumption of luxury goods for personal or ritual usage.[32]

Contemporaries labelled issues purposefully as new or old to situate tools, weapons and machines, large-scale technical projects, and practical and managerial production methods within complex ethical, social, or individual concerns. In the *Wujing zongyao* (Collection of the most important military techniques, 1044) compiled by Zeng Gongliang (998–1078), Ding Du and Yang Weide (n.d.), military tactics were endorsed with references to ancient times, classical studies, and the idealized Zhou state (fifth–seventh centuries), but the text also promoted the use of novel improved weaponry. In many places, soldiers actually engaged in war employed the latest products and most innovative technologies, while the civilian elites claimed to have superior knowledge about military principles, drawing on examples from history.

References to the past in this era both in the West and East bestowed gravitas on new ideas or products. In philosophical debates on *wuyuan*, the 'origin of things', however, Chinese scholars gave novelties a past primarily to substantiate their cultural relevance. Thus, Lü Bi in the seventeenth century explained the south-pointing chariot – a mechanism that was meant to keep pointing south whichever direction the vehicle turned – as the product of a long process of knowledge accumulation and successive subtle and substantial innovations by sages who had invented the wheel, the chariot, and the needle that again were based on earlier developments such as the bi-disc, or the spear. Lü recalled this nexus as a reminder for rightful and moral rulership in full awareness that the knowledge to construct this machine was in fact already lost.[33]

32 Themes such as the value of work were anchored in Chinese classics of the pre-imperial period like the *Li ji* (Book of Rites) or the *Kaogong ji* (Artificers Record). For Europe, see George Ovitt, *The Restoration of Perfection: Labor and Technology in Medieval Culture* (New Brunswick: Rutgers University Press, 1987).

33 Lü Bi (seventeenth century), *Shiwu chulüe* (Preliminary Summary of Things and Affairs), Siku quanshu cunmu congshu, zibu 98 (Ji'nan: Qi lu shushi chubanshe 1995 [reprint of 1637 edition]), ch. 33, 13a.

Within these debates on the 'origin of things' Chinese scholars pondered technologies and innovation as admonitions and chances for human development.[34] Imperial historiography often invoked technological innovations within a rhetoric of political and cultural dominance. Mythical figures such as the Yellow Emperor gave the civilized inhabitants of Chinese culture the implements and methods to write, print, and construct a boat or cart, while barbarians clothed themselves with furs and feathers, hunted for food or collected wild berries. Similarly, European scholars situated artisans' knowledge within general accounts of human understanding and endeavour.[35]

In China, artisanal communities informed such discourses even though historiography has highlighted the scholarly role. As a general rule, craftsmen seem to have disguised their original trade when rising into higher ranks. Artisans participated in and affected literati thought; natural philosophers brought new developments and patterns of thought into the mainstream, pondered practices and legitimized new utensils.

Technical treatises, visual representations, and scale models

Since the time of Michael Polanyi, numerous studies have indicated the role of practice and explained how 'tacit' knowledge plays an important role in the recognition of technological development and historical reflections on it. Historians of technology have not yet studied the diverse forms of artisanal expertise systematically. However, even if codification in everyday activities embedded in the diverse traditions of local family communities or regional expert communities might not be as visible as knowledge codified in writing or drawing, it doubtless secured the application and transmission of technical knowledge in various world regions. Stunning works of art produced from a wide range of materials such as metals, stone, glass, wood, and ceramics resulted from this kind of expertise. Technical instruction based on imitation rather than on specialized vocabulary and teaching institutions could cross language borders, as long as the persons involved agreed on the transmission of the expertise.

34 Martina Siebert, 'Making Technology History', in Schäfer, *Cultures of Knowledge*, 253–81, here 268.

35 Elspeth Whitney, *Paradise Restored: The Mechanical Arts from Antiquity Through the Thirteenth Century* (Transactions of the American Philosophical Society, 80[1]; Philadelphia: American Philosophical Society, 1990).

Between 500 and 1500, the makers and creators of technologies conveyed their knowledge within collaborative networks. They learned from each other and through the interchange of samples, tools or products, stabilizing their trade with ritual, social and cultural practices. Across Eurasia technical procedures were also shared through text and images, a development that formed part of the far-reaching changes in communication induced by the spread of paper from China over to the Islamic world to Europe during the Middle Millennium. Textual scripts aimed to preserve and transmit practical knowledge within a scholarly realm and elite context. To what extent texts and images also served to instruct, or were directly employed in the realization of technical projects, is still open to debate.

Across cultures, elites demonstrated a keen interest in the circulation of agricultural expertise. In China rulers pondered the documentation of farming techniques, along with spinning and weaving, as issues of societal and individual moral development in state and philosophical contexts, making agronomy a 'science of the state'.[36] In the Islamic world, officials of the Muslim caliphates equally attempted to advance new cultivation methods.[37] In Europe, by contrast, treatises on agronomy, closely linking to Roman antiquity, portrayed ideals and did not ponder practical application.

From the ninth century, scholars writing in Arabic also produced illustrated treatises on mechanical contrivances, automata, and water-lifting devices. Such works brought attention to individual expertise and ability. Rulers commissioned compilations on technical issues to substantiate their own mandate over a field of knowledge. Fifteenth-century Italian authors addressed elites in treatises on architecture and civil and military mechanical engineering. European monks described the material properties, formulae, and procedures of crafts that artisans had previously only transmitted orally and visually from father to son, or from master to disciple. In the twelfth century the German Benedictine priest known by the pseudonym 'Theophilus' provides in a work called *Diversarum artium schedula* (List of various arts) instructions for religious decorative art including painting, metalwork,

36 For a discussion of agricultural treatises and their content, see Francesca Bray, *Science and Civilisation in China, vol. VI, Part 2: Agriculture*, ed. Joseph Needham (Cambridge University Press, 1984).

37 Karl W. Butzer, 'The Islamic Traditions of Agroecology: Crosscultural Experience, Ideas and Innovations', *Cultural Geographies* (January 1994): 7–50; Michael Decker, 'Plants and Progress. Rethinking the Islamic Agricultural Revolution', *Journal of Global History* 20 (2009): 187–206.

stained glass windows, organ-building, and casting bells. The author justifies his interest as a form of worshipping God, probably responding to contemporary critics who condemned such superfluous luxuries. In China, such works were written by scholars and artisans advancing into officialdom. Liu Ji (1311–75) in *Duoneng bishi* (The many doings of vulgar affairs) gave an encyclopaedic overview of dyeing procedures, medicinal mixtures, and cooking recipes, alongside instructions for divination, farming, and the use of utensils.

Authors and states that promoted texts as a way of disseminating technical information were well aware of their audiences. Their rhetoric expressed a keen concern for openness, and at other times emphasized secrecy for ideological or marketing reasons. Works that stressed the need for open access still silently withheld crucial information that would have enabled the reader to put the process into practice.[38] The privileges for (mostly mechanical) inventions granted by territorial powers north of the Alps in mining regions and Italian city-states of the late fifteenth century are one example, highlighting the growing importance of written documents for the legal institutionalization of innovative activity that scholars usually situate in the early modern era.[39]

In general, technical instruction remained firmly rooted in the arts and crafts, and was not yet dependent on the study of mathematically formulated natural laws and curricula in institutions of higher technical learning.[40] Many cultures employed basic rules of practical mathematics, often supported by simple means such as ropes and templates, most frequently to determine the sizing of technical objects or in architecture. Small groups of scholars in all cultures reflected on basic mechanical phenomena, most notably those connected to the relation of weight, time, and force in the application of simple machines like the lever and the balance. Related theoretical developments featured most prominently in texts of Arabic-writing scholars extending the mechanical knowledge of their Greek and Hellenistic predecessors. In the Late Middle Ages, a few European scholars recognized these works, which by the sixteenth century became one of the cornerstones of

38 Pamela O. Long, *Openness, Secrecy, Authorship: Technical Arts and the Culture of Knowledge from Antiquity to the Renaissance* (Baltimore: Johns Hopkins Press, 2001).

39 Carlo Belfanti, 'Guilds, Patents, and the Circulation of Technical Knowledge', *Technology & Culture* 45 (2004): 569–89.

40 Bert De Munck, Steven L. Kaplan and Hugo Soly (eds.), *Learning on the Shop Floor: Historical Perspectives on Apprenticeship* (New York, Oxford: Berghahn, 2007).

pre-classical mechanics. But innovation in medieval technology was nowhere dependent on such theoretical or scientific reflections.

When knowledge had to be made available across large areas or time-spans, artisans and elites functionalized texts within a variety of media such as sketches, models, or plans. Sometimes, elite actors involved in technical enterprises decided that models or migrating artisans would be more effective than texts. For example, Song officials favoured the dissemination of models (*yang*) over written instruction when asked to promote the rather basic tool of the foot plough. The first Ming ruler Zhu Yuanzhang (1328–98), believing in person-to-person contact, obliged artisans to travel and exchange their skills within state-owned manufactures.[41] In a quite different environment, European guilds in the Late Middle Ages fostered journeymen's travel as a means of acquiring foreign knowledge.[42]

Beyond Europe, the role of modules, templates, and scale models has only been scantily studied. Generally, the use of such media increased with the size of technological sites, or where technical expertise met courtly demands. European masons, for example, made drawings directly onto building stonework, tracing floors and setting out lines and curves to guide the cutting and placing of individual components. At the Dunhuang grottoes in Central Asia, artisans systematically employed templates and plans to copy and reconfigure wall paintings and plaster sculptures. In the fifteenth and sixteenth centuries, Ottoman architecture used model books to advertise and realize ornamental building decorations with very complex mathematical and geometrical structures.

In China, Europe, and the Islamic world actors employed scale models in hydraulic works, building construction, or astronomical instruments.[43] Whenever investment was high and the outcome needed to be secured, individuals and state actors ordered the construction of models prior to production, as the high court official and polymath Shen Kuo (1031–95) attested: 'The assistant official of the imperial Yanhe palace oversees the production of a wooden model for the armillary sphere.' The source commented 'according to the *Tianwen zhi* (Record on astronomy) a wooden

41 For example, see the set-up of state-owned silk manufacture: Schäfer, *Des Kaisers Seidene Kleider*, esp. chs. 2 and 3.

42 Reinhold Reith, 'Circulation of Skilled Labour in Late Medieval and Early Modern Central Europe', in Stephan R. Epstein and Maarten Prak (eds.), *Guilds, Innovation, and the European Economy* (Leiden: Brill, 2008): 114–42.

43 Klaas Ruitenbeek, *Carpentry and Building in Late Imperial China: A Study of the Carpenter's Manual Luban Jing* (New York: Brill, 1993): 49–67.

model has to be produced so that mistakes can be corrected.'[44] In about 1158, the provincial governor Zhang Zhongyan, who was then in the service of the Jurchen Jin, 'began to build ships. The artisans did not know how. So Zhongyan personally made a small boat several thumb-widths long, fitting it all together perfectly from bow to stern without using glue or lacquer and calling it his demonstration model. The astonished artisans showed him the greatest respect.'[45] Italian sources increasingly mention architectural and machine models around 1400 and their use has been closely linked to Renaissance court culture and new developments in the organization of large-scale building processes.[46] Ottoman architects at the same time also seem to have built on a tradition of planning using both drawings and models.

By the Song era, Chinese scholar–officials regularly drew sketches or commissioned samples. The high minister and polymath Su Song (1020–1101) listed all elements of his new clock tower in the *Xin yixiang fayao* (New design for an armillary [sphere] and [celestial] globe, printed in 1094) (see Figure 12.1). A later edition shows meticulously illustrated gears, wheels, and axles to evince the expertise that went into this project and justify the substantial investment. Su Song's apparatus was built, but then the Jurchen conquered the Song capital, and dismantled the clock tower for transportation to their capital Kaifeng. They were not able to restore it to functionality again.[47]

In the printing boom of the Song the relation of illustrations and textual means for the communication, construction, and memorization of knowledge became a matter of scholarly debate.[48] State managerial literature on crafts and technologies compiled during this era achieved model character for later eras. The prime example is the Chinese classic text of architectural writings, the *Yingzao fashi* (Building Standards) of the Song dynasty that standardized building methods, terminology and construction elements within imperial

44 Tuo Tuo, *The History of the Song*, ch. 162, 952.

45 Tuo Tuo, *Jin shi* (History of the Jin [Dynasty 1125–1234]) (Beijing: Zhonghua shuju, 1975 [1343]), ch. 79, 9a.

46 Marcus Popplow, *Models of Machines: A 'Missing Link' between Early Modern Engineering and Mechanics* (Berlin: Max Planck Institute for the History of Science, Preprint 225, 2002).

47 For a discussion of Su Song's efforts see Joseph Needham, *Heavenly Clockwork: The Great Astronomical Clocks of Medieval China* (Cambridge: Published in association with the Antiquarian Horological Society at the University Press, 1960).

48 Francesca Bray, Vera Dorofeeva-Lichtmann and Georges Métailié (eds.), *Graphics and Text in the Production of Technical Knowledge in China: The Warp and the Weft* (Leiden: Brill, 2007).

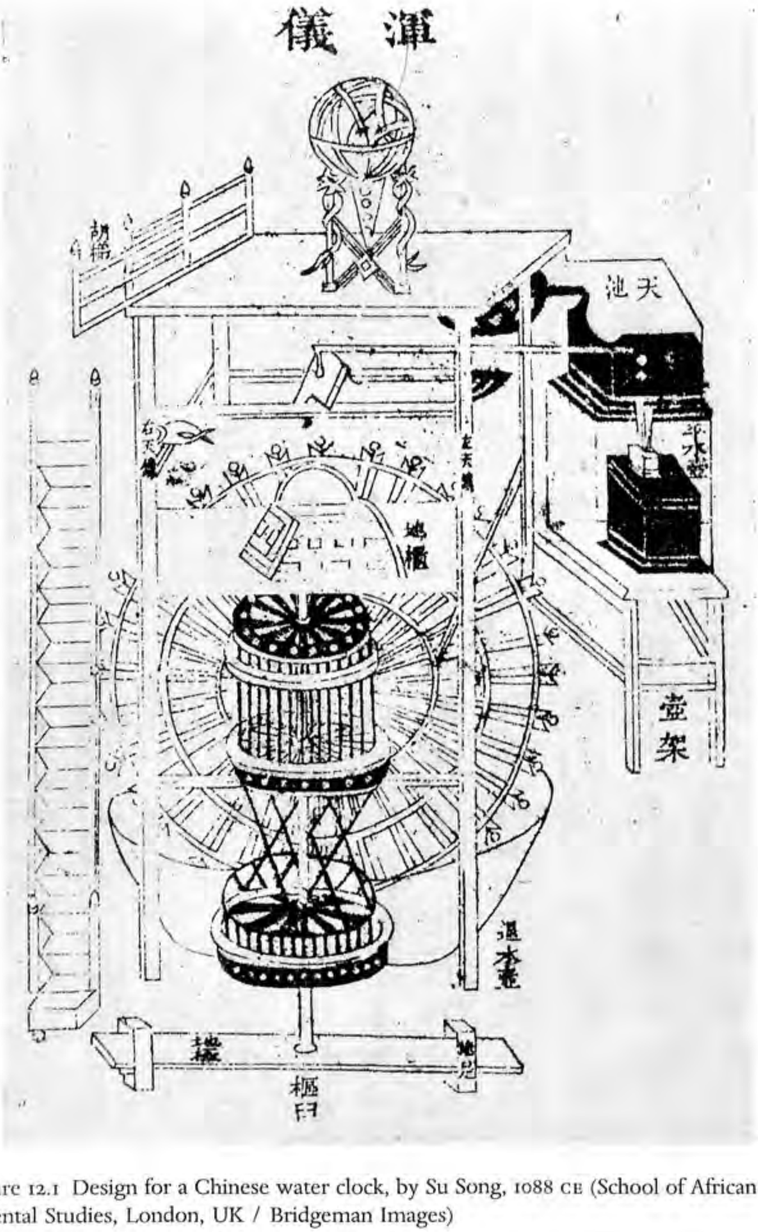

Figure 12.1 Design for a Chinese water clock, by Su Song, 1088 CE (School of African and Oriental Studies, London, UK / Bridgeman Images)

architecture, based on earlier handbooks (such as the *Mujing* [Classic on Carpentry]).[49] Published during the Song era, the *Yingzao fashi* functioned as a managerial rather than a technical guide, working with illustrations and texts. Translating craftsmen skills into the poetic language and concepts of a literati world, this book subtly demonstrates how learned and non-learned cultures intermingled in the building trade. In contrast, the famous notebook of Villard de Honnecourt (*c.* 1220), whose sketches include construction details of several French cathedrals, is of a more informal nature (see Figure 12.2).[50] More elaborate architectural treatises, following the ancient role model of the Roman architect Vitruvius, were not composed until the fifteenth century in Europe.

Much of what we know about technology originates from the products of technical processes, i.e. works of art, religious paraphernalia, or everyday objects. Archaeologists have unearthed on-site technical changes in house building, oven construction, metalworking, and textile production that are not evident in contemporary texts or illustrations. These objects are another avenue into histories of technology, even though their interpretation is difficult. Remnants demonstrate a diversification of loom technology in the European Middle Ages; they shifted from vertical to horizontal forms, while the frame size expanded, possibly following the silk looms employed by Arab artisans in al-Andalus and Sicily. Today, anonymous technical achievements that have actually survived, such as the water-supply system of Machu Picchu, and the famous eighth-century bridge equipped with iron chains in China, are respected and admired. Such artefacts give us another view, although their contextualization within a process of change is difficult. In contrast, attaching a named expert to technical achievements usually secures attention to projects whose realization is difficult to substantiate. Engineer–authors such as the Musa brothers (Banu Musa) or al-Jazari are known in the Islamic world and beyond, although their machines have not survived.

In sum, writing enhanced the role of practical knowledge and the practitioner's social status, and practical knowledge and practitioners contributed to the value of writing. Artisans deliberately identified themselves as scholars, whilst scholars substantiated their practical abilities by writing about them. Before 1500 technical instructions were based on imitation and

49 Feng Jiren, *Chinese Architecture and Metaphor: Song Culture in the Yingzao fashi Building Manual* (Honolulu: University of Hawai'i Press, 2012).

50 Carl F. Barnes (ed.), *The Portfolio of Villard de Honnecourt* (Aldershot: Ashgate, 2009).

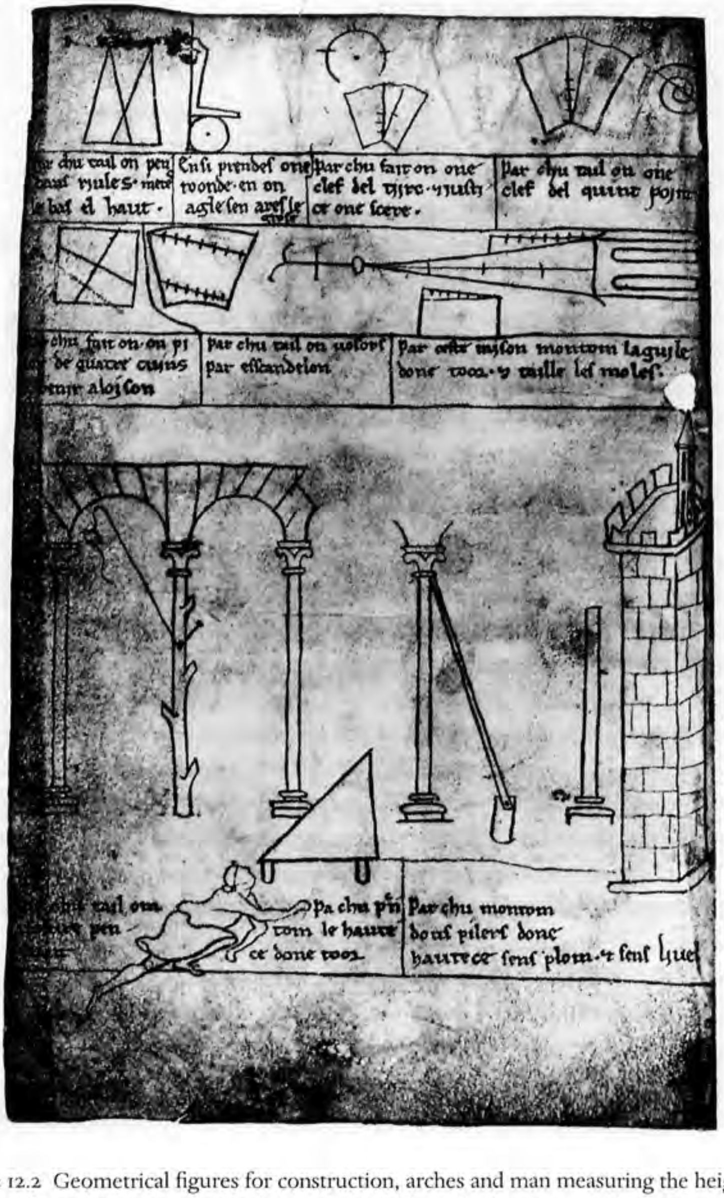

Figure 12.2 Geometrical figures for construction, arches and man measuring the height of a tower (facsimile copy, pen & ink on paper), Villard de Honnecourt (*fl.* 1190–1235) (Bibliothèque Nationale, Paris, France / Giraudon / Bridgeman Images)

not formal teaching institutions; practical knowledge cultures combined social memory systems, and various media. Written documents played various roles.

Transmission processes

Although models of centre and periphery, transfer and resistance have been brought into question, global histories of knowledge and technological change still remain grounded in the identification of distinct, separate units of culture interacting in contact zones, that is social spaces where cultures, represented by individuals or groups, meet, and connect with each other. Power relations, and mechanisms of trust, truth and morality affect the exchange, appropriation, or rejection of knowledge. Political, religious and social powers shaped major directions.

In terms of webs of technological exchange, the world of the Middle Millennium was still one of land masses: connections were made by land or along coastal lines. Before 1500, the peoples of the Americas employed sets of technological tools, techniques, and expertise largely independent of those of Afro-Eurasia, as did the people of Australia. This era therefore contrasts with the era after 1500, in which technology spread by seafaring and colonialism on a global scale.

For a long time, historians of technology equated transmission processes with the rise of European power at the end of the sixteenth century. More recently, they have acknowledged the reciprocity of exchange, and the focus of studies has moved from transmission to circulation and the processes of mediation, adaptation, and translation. Considerable exchange of merchandise and technical ideas over large distances across Eurasia marks the Middle Millennium, but mostly the exchange happened from one neighboring power to the next. Regions fostered close linkages informed by diverse ideas and products, then developed quite autochthonous technological cultures. Northern European, Mediterranean, Near Eastern, East or Southeast Asian, African, and North or South American cultures each produced distinctive forms of coastal ships with specific features that existed nowhere else. Chinese shipbuilders built large ships with watertight sealed compartments that allowed long-distance trade and explorations to Arabia and the East African coasts. Such exchanges were still extraordinary, and thus, while building technologies travelled, most shipyards continued to produce ships for distinctive regional purposes and conditions and thus local styles were maintained. Towards the end of the period the Portuguese started to mix

European traditions of shipbuilding, creating caravels and carracks that enabled journeys across the Indian Ocean and eventually to the Americas.

Transmission happened by chance within trade contexts, through individuals, or through political initiatives.[51] Territorial powers attracted and recruited foreign technical experts for civil and military purposes. Courts and communal administrations offered privileges to artisans with desired skills. Periods of unified political administration such as the Pax Mongolica facilitated the rapid travel of gunpowder expertise. Qubilai Khan (1215–94), enforced mobility on experts of all regions of Eurasia through patronage and slavery. The caliphs exchanged hydraulic experts, moving them between regions as distant as the Levant and al-Andalus.[52] The medieval Mediterranean was another contact zone of diverse cultures of southern Europe, Byzantium, and the Islamic world, drawing on the material and cultural remains of Roman, Hellenistic, or Egyptian times. Spanish irrigation techniques were a legacy of Rome and previous exchanges with North Africa.[53] Technological exchange was therefore multidirectional and multifarious, embedded in the transfer of material culture, from luxury to everyday goods, works of art and commodities such as silk and rice. Times of war could disrupt channels of knowledge transmission but they could equally open up new ones. Political ruptures such as the crusades have been discussed as important catalysts for intercultural knowledge transmission. Crusaders imported traits of Near Eastern fortress architecture to Europe.

Technologies usually migrated together with the people who used them, who crossed cultural and geographic boundaries with political or religious incentives. These people often attempted to maintain coherence and continuity across regions and time, whilst being forced to compromise because of a lack of locally available materials, skills, or financial resources. Religious communities, for instance, fostered the development of such technical expertise. The Cistercian order in Europe trained monks in hydraulic works, advanced agriculture, and ironworking, and then disseminated these skills through its dense monastic network. Religious institutions promoted technologies also for financial incentives. Buddhist monasteries during the Tang

51 Liliane Hilaire-Perez and Catherine Verna, 'Dissemination of Technical Knowledge in the Middle Ages and the Early Modern Era', *Technology & Culture* 47 (2006): 536–65.

52 Yassir Benhima and Pierre Guichard, 'Quelques aspects des échanges techniques en Méditerranée occidentale à la fin du Moyen Âge', in *Mélanges Halima Ferhat* (Rabat: Institut des Études Africaines, 2005): 73–112.

53 Andrew I. Wilson, 'Classical Water Technology in the Early Islamic World', in Christer Bruun and Ari Saastamoinen (eds.), *Technology, Ideology, Water: From Frontinus to the Renaissance and Beyond* (Rome: Institutum Romanum Finlandiae, 2003): 115–41.

era, for example, engaged their staff systematically in the production of oils and silk.[54] New illusionary painting techniques and items such as the eternally burning lamp circulated and the chair was introduced to China and then onwards to Goguryeo Korea and Heian Japan (794–1185). The effect was dramatic. Tiered seating orders, from the mat and squatting to an elevated position, became indicators of social status throughout Asia.[55] The elevation of the human body impacted ideas about the body itself, the universe, and the order of the cosmos. How these developments in turn affected technological matters is still barely understood.

Ruling powers and technological innovation

Territorial powers and their political infrastructure between 500 and 1500 created, selected, documented and preserved historical records about technologies, artefacts, and implements. Hence, even though developments in fact often occurred bottom-up, we know more about the political rhetoric of technologies and individuals who were said to have created, discovered or recorded technologies or brought innovations to effect, than actual practitioners and production. European historiography for a long time tended to emphasize the creative genius. The nature of the available sources in Asia is such that communal issues and state activity are highlighted. In both cases, courts and courtiers are the protagonists who spurred technological changes within hegemonic structures or through financial incentives, rights of settlement, or social security and status. Elite fashions and desires had both local and far-reaching impact. Elites in the Muslim world, for example, initiated the local development of delicate mechanisms and sensitive control systems for water clocks, fountains, toys and automata as well astronomical instruments like the astrolabe, which prompted similar aspirations in Europe.[56] A demand for gold among the European ruling classes or copper in the Muslim realm stimulated mining activities as far afield as Africa.

In the Near East, Africa, Europe, and Asia, imperial and religious patronage systems existed, through which subtle shifts in material culture as well as

54 Jacques Gernet, *Buddhism in Chinese Society: An Economic History from the Fifth to the Tenth Centuries*, trans. Franciscus Verellen (New York: Columbia University Press, 1995): 192–3.

55 For the chair and everyday culture during the Tang see Charles D. Benn, *Daily Life in Traditional China: The Tang Dynasty* (Westport, CT: Greenwood Press, 2002): 85. For the spread to Japan see Fabio Rambelli, *Buddhist Materiality: A Cultural History of Objects in Japanese Buddhism* (Stanford University Press, 2007).

56 For an overview of sources see Hill, *Medieval Islamic Technology*, 167–86.

daring technical projects were realized. In the seventh century, religious leaders promoted bronze workshops in Sotlaniganj in Bihar and the monastic centres of Nalanda or Antichak to boost the size of their bronze statues.[57] Excavations and artefacts found in present-day Nigeria from the fourteenth century attest to the large-scale exploitation of copper resources, the development of bronze casting and smelting techniques for the production of coins, ritual and decorative items, and trade in resources.[58] Gothic cathedrals,[59] Indian mausoleums, temples, tombs, rulers' palaces and ritual sites – in Mesoamerica, Cambodia and China – were places where materials and their properties were tested in new contexts. Palaces and monasteries, once built, were constantly repaired, or modified. Like arsenals, wharfs and mines, construction sites constituted centres of innovation where aristocratic, religious, and military elites, scholars, traders and artisans interacted, debating old and new techniques.[60]

State or elite interests brought technologies into effect through administrative control. Muslim rulers promoted irrigation schemes along the Mediterranean coasts and the Near East within state-organizational frameworks. The Tang, Jin, Liao, Song, Yuan and Ming dynasties in China planned waterways and dykes, sometimes locally and then again in central state institutions, on a scale that would have been unimaginable within the politically fragmented landscape of medieval Europe.[61] The Grand Canal, whose oldest parts date back to the seventh century, provided an inland route for transporting the annual grain taxes from Hangzhou to the capital Kaifeng, once it was provided with pound locks in the tenth century. The Song preferred the Grand Canal as a long-term solution to recurring costly military campaigns against the pirates that hampered sea trade.[62] Technological choices thus rested on a multitude of considerations.

57 Niharranjan Ray, Karl J. Khandalavala and Sadashiv Gorakshkar, *Eastern Indian Bronzes* (New Delhi: Lalit Kala Akademi, 1986): 96.

58 P. R. Schmidt, *Iron Technology in East Africa: Symbolism, Science, and Archaeology* (Bloomington: Indiana University Press, 1997).

59 Lynn T. Courtenay (ed.), *The Engineering of Medieval Cathedrals* (Aldershot: Ashgate, 1997).

60 See Pamela O. Long, *Artisan/Practitioners and the Rise of the New Sciences, 1400–1600* (Corvallis: Oregon State University Press, 2011), ch. 4.

61 For water-management in medieval Europe see P. Squatriti (ed.), *Working with Water in Medieval Europe: Technology and Resource-Use* (Leiden: Brill, 2000); R. Magnusson, *Water Technology in the Middle Ages: Cities, Monasteries, and Waterworks after the Roman Empire* (Baltimore: Johns Hopkins University Press, 2001).

62 In the *Ru Shu ji* [Record of a Trip to Shu] Lu You (1125–1210) recounts 153 days of a 157-day-long travel along the Grand Canal and the Changjiang river. For an English

Huge technological projects such as the Chinese Grand Canal also took place during times of turmoil. Anxieties concerning food, shelter, and life led elites to concern themselves with practical matters or try out new ways. In the fragmented Song dynasty, when the Chinese state was weak and threatened by tribes in the north, a meritocratic elite became increasingly interested in technological change and thus documented it. Social and political pressures were at the heart of the ferocious struggle among late medieval Italian cities and city-states that fostered their interest in military and civil engineering and led to splendid, innovative architectural works.

Between 500 and 1500 state-directed technical projects can only be understood by examining the social, political, and ideological concerns that motivated them. The large-scale hydraulic projects of the Song and Yuan dynasties helped to transform swamps and wilderness into cultivated fields, but dyke and canal construction, in constant need of labour, could also provoke social unrest from potentially hazardous groups such as immigrants and exploited farmers. The high chancellor of the Song dynasty, Ding Wei (962–1033), thus explicitly described hydraulic projects with military rhetoric, as forming ramparts against intruding Northerners, contextualizing such projects as an issue of political stability.[63]

A comparison between written and artefactual evidence often shows that elites overemphasized the local adoption and regional expansion of what an era defined or used as its significant technologies. In the case of China, studies of sites have helped to deconstruct the myth of omnipresent state power, demonstrating that localities adjusted technologies to suit their own purpose, rather than adhering to imperial styles, and elite ideologies or methods. The local aim was to make things work. Despite their rhetoric of control, the Song and Ming elites in fact often kept a loose rein on local developments.[64] Even with a unified rule and centralized administration, the landscape of Chinese technologies was probably as scattered and diverse as it was in the fragmented political scene of Europe. Meso- and South American rulers did not apply standardized territorial power in the realm of

translation see Philip Watson, *Grand Canal, Great River: The Travel Diary of a Twelfth-Century Chinese Poet* (London: Frances Lincoln, 2007).

63 Christian Lamouroux, 'From the Yellow River to the Huai: New Representations of a River Network and the Hydraulic Crisis of 1128', in Mark Elvin and Liu Ts'ui-jung, *Sediments of Time: Environment and Society in Chinese History* (Cambridge University Press, 1998): 554.

64 Peter Bol, 'The Rise of Local History: History, Geography, and Culture in Southern Song and Yuan Wuzhou', *Harvard Journal of Asiatic Studies* 61,1 (2001): 37–76.

technology, and the Islamic world relied on the cooperation of a number of ever-shifting local or intermediary actors.

Diverse agents of local or regional power played a role in technical innovation through measures such as water and waste management, and by investing in material equipment to achieve cultural supremacy. In Europe, mechanized clockwork spread in the fourteenth century not primarily because of monks' or merchants' needs for more precise time-keeping, but because towns became enthusiastic about an artefact that signalled the time acoustically and visually, turning clocks rapidly into a status symbol. Clerical communities invested in astronomical clockworks as visualizations of the fascinating regularities of the universe created by God.[65] Su Song's much earlier monumental astronomical clock of 1088 instead manifested a dynastic effort to legitimate Chinese rulership. Within a tradition of manufacturing acoustic bells, Su Song developed his mechanism as a way to harmonize the universe's visible and invisible realms and find order. The clock demonstrated to the populace, through sound and sight, that their ruler was in charge of time, and knowledgeable about how to attune the human to the heavenly realm.

Only occasionally do sources allow a glimpse of non-elite groups such as village inhabitants who came together to carry out large-scale works, including settlers in late medieval Holland who organized land reclamation at the local or regional level.[66] But these non-elites must be understood as the basis of complex organizational schemes that linked territorial powers, local entrepreneurs, and advanced technical expertise, for example, in central European mining regions. In the end, the historically visible figures were often those who managed to bring an innovation to effect or to set the standards in a particular location or region by selecting from what others had already developed, or by imposing their individual tastes through social or political means.

Elites often acted as the catalysts for innovation, but practitioners implemented them. Much depended on pragmatic considerations of economic benefit such as the fact that medieval English peasants accepted horses as working animals. In this regard research has proven that less highly educated groups in pre-industrial Europe were *not* necessarily hostile to innovation.

65 Gerhard Dohrn van Rossum, *History of the Hour: Clocks and Modern Temporal Orders*, trans. Thomas Dunlap (University of Chicago Press, 1996).

66 William TeBrake, 'Hydraulic Engineering in the Netherlands during the Middle Ages', in Squatriti, *Working with Water in Medieval Europe*, 101–27.

From the High Middle Ages onwards craft guilds actually fostered or sustained technological development.[67] In fact, most artisanal gatherings in any culture, whether organized along communal rules or by way of kinship, dealt pragmatically with novelty or traditional techniques and products, seeing which best protected their trade and secured individual survival. Clearly for contemporaries of the Middle Millennium novelty was not 'global', but locally distinct and ephemeral. New developments lingered for a while, or were even invented several times, before they took root, turned into traditions – and eventually gained historical attention.

Environmental factors

As historians of technology have come to explore the social construction of technology, environmental historians have started to consider the physical and natural conditions affecting human technological endeavour. Changes in environmental circumstances or human migration into areas that required different equipment were at least as important as political and institutional frameworks in stimulating technological innovation. Due to energy needs in the porcelain industry, urbanization, shipbuilding or husbandry, whole regions were deforested. Cattle and horses accelerated trade and communication channels, although this also meant that large areas of arable land had to be relinquished for grazing or the growing of fodder crops.

The Middle Millennium is mainly depicted as a phase of slowly accelerating regional shifts in land usage, food-production methods, and patterns of energy and resource consumption. People are seen as having ambivalent roles, being both affected by nature and reacting to or being conditioned by their physical environment whilst also impacting their physical environment through their own intervention. Technology and environment were directly linked, affecting each other often immediately and within a local or regional, rather than global scale. One of the most notable environmental events of this era was the Medieval Climate Optimum – a period of favourable natural conditions for agriculture in parts of the northern hemisphere between the tenth and the thirteenth centuries. The increase in food resources led to accelerated population growth in both Europe and Asian regions such as Song China. By the fourteenth century, average temperatures dropped again and plague ravaged through much of Eurasia, slowing the demographic accretion.

67 Epstein and Prak, *Guilds*, Introduction.

The relation between environmental change, crisis and technology in this period is far from understood: which came first and which afterwards? As Radkau notes in this volume, people reacted to local weather, not to global climate; they pondered local crop failure, and water shortage, but rarely noticed desertification or deforestation in regions far away. In many cases, attention is turned to what we now identify as technology when cultures struggled to find methods of recruiting larger amounts of energy, and worked to expand resources of food and materials for use in producing the arts and crafts.[68] The limited availability of energy, food, water, and shelter set limits to population density, urbanization, and the increase of artisanal processes.[69] In some cases, ritual and social constraints set in, or people moved. In other cases technological change was brought about. Most cultures around the world used non-fossil fuels such as wood, dung or peat for fire and heat up until the eighteenth century and far beyond. One exception is Song China, where coal was employed to process iron for weaponry and, as people attempted to get rid of impurities in the coal and improve energy output, coke production developed. After the Mongol invasion in the thirteenth century, coal exploitation stopped, and was not taken up again on a large scale until the nineteenth century.

In historical discourse, the environment plays a role as the grid along which technologies circulated. Monsoon winds, sea currents, valleys, and mountains directed the flow of the human race. Rivers were major thoroughfares, because water transportation was often the cheapest and fastest way to move goods and people. Humans pushed the environmental limits by technological means, building channels into rivers to redirect their flows or enable new connections. To counter floods, rulers initiated the construction of dykes, while other communities installed hydraulic systems to provide arid zones with water for agriculture. In this era, humans were strongly bound to local environmental conditions in their use of resources. Building practices evolved from the qualities of locally available building materials, yet when people moved, they took materials, plants or techniques to a new locale. In this way, porcelain spread and the red dye called sappanwood was transmitted from India and Malaya throughout Asia and northern Europe.[70]

68 Smith and Wolfe (eds.), *Technology and Resource-Use*, 464.

69 Malanima, *Pre-modern European Economy*, 49–94.

70 Regula Schorta and A. D. H. Bivar, *Central Asian Textiles and their Contexts in the Early Middle Ages* (Riggisberg: Abegg-Stiftung, 2006): 44.

The soil itself influenced technological change. Imported new crops, such as fast-ripening Vietnamese varieties of Champa rice in eleventh-century China, brought about dramatic changes, affecting the balance of nature as well as food production and consumption. Economic historians and theorists have intensely debated the causes and consequences of the different organizational responses made by China and Europe to the population pressures they faced during the Medieval Climate Optimum, when the Chinese developed a labour-intensive method of irrigated agriculture and Europeans a capital-intensive form of 'dry' agriculture. Nevertheless, similar tools and mechanisms were sometimes applied in quite different environments. The mouldboard plough was effective both for working heavy European soils and for preparing underwater rice paddies in China. Once in use, such technology could stimulate distinct forms of social cooperation. For example, because turning ploughs in heavy soil was difficult, in Europe land was ploughed in long strips with no barriers between them, and villagers decided as a group what crops to plant.

Historians of technology and the environment contend with issues of cause and effect. In global cross-cultural comparisons, environmental factors can explain technological choices. Camels proved to be an advantageous form of transportation in the arid and semi-arid zones of Africa, Arabia and Central Asia, because they could survive despite water shortages and did not require any investment in infrastructures such as roads. Beginning around 500, a new kind of saddle allowed them to be used for transporting heavy loads and in military battles, changing the pace and scope of communication in Northern Africa and Central Asia. Considering their suitability to specific environmental circumstances, camels were thus not technologically inferior to carts.

Conclusion

Technological innovation was a ubiquitous global phenomenon between 500 and 1500, yet its appearances and impact varied greatly in different world regions and cultures of knowledge. Most scholars of global history today agree that the 'great divergence' in the sense of a particular European development into industrialized modernity was not yet visible in 1500. Regions manifested diverse modes of technological prowess, and competed primarily with their neighbours in terms of engineering achievements, artisanal knowledge, and agricultural production. Regions acted on a global scale through linkages with their neighbours rather than direct interchange.

Many changes appear gradual when examined close up, yet clearly technology in 1500 differed remarkably from that employed around 500 across Eurasia. By 1500, technologies often developed through the merging of several regional traditions, which were adopted and adapted to each locale's economic, social, and environmental conditions.[71] Political or religious structures framed the activity, but artisanal experts and practitioners held the basis of technical knowledge and stabilized its circulation. Future research should attempt to write a history of technological knowledge that integrates the diverse cultural discourses on forms of knowledge representation, ideas about innovative forces, and historical choices of technologies.

If we accept that technology and innovation are historically contingent and that cultures employed them in many different ways, it becomes difficult to maintain the idea that certain cultures were hostile towards technology or ignorant of it, as has been argued for Christianity and occasionally also for Asian or African cultures in this era. In technological terms, the world of the Middle Millennium was dynamic and multifarious and people dealt with technology and innovation both deliberately and playfully. Sometimes they praised what was novel, and sometimes they invoked an ideal past. It was therefore an age that paradoxically used innovation for both reform and the continuation of traditions. People considered technological development not as a value in its own right, but as an agent of their daily life and thought.

FURTHER READING

Adas, Michael. *Machines as the Measure of Men: Science, Technology, and Ideologies of Western Dominance*. Ithaca and London: Cornell University Press, 1989.

Astill, Grenville and John Langdon, eds. *Medieval Farming and Technology: The Impact of Agricultural Change in Northwest Europe*. *Technology and Change in History*, vol. 1. Leiden: Brill, 1997.

Basalla, George. *The Evolution of Technology*. Cambridge University Press, 1988.

Benn, Charles D. *Daily Life in Traditional China: The Tang Dynasty*. Westport, CT: Greenwood Press, 2002.

Bray, Francesca. *Technology and Gender: Fabrics of Power in Late Imperial China*. Berkeley and Los Angeles, CA: University of California Press, 1997.

Bray, Francesca, Vera Dorofeeva-Lichtmann and Georges Métailié, eds. *Graphics and Text in the Production of Technical Knowledge in China: The Warp and the Weft*. Leiden: Brill, 2007.

Burke, Edmund, III. 'Islam at the Center: Technological Complexes and the Roots of Modernity', *Journal of World History* 20,2 (2009): 165–86.

71 Feza Günergun and Dhruv Raina, *Science between Europe and Asia: Historical Studies on the Transmission, Adoption and Adaptation of Knowledge* (New York: Springer, 2011).