1 Cathedrals

They climbed on sketchy ladders towards God,
With winch and pulley hoisted hewn rock into heaven,
Inhabited the sky with hammers, defied gravity,
Deified stone, took up God's house to meet him,
And came down to their suppers and small beer ...

John Ormond, *The Cathedral Builders*

The Cathedral

This is the Gothic cathedral, the marvel that inspired Ormond's poem. The one in the picture (Figure 1.1) is perhaps the grandest of them all: the Notre Dame Cathedral at Chartres, south-west of Paris. It is a breathtaking accomplishment: 130 meters in length, it would cover a Manhattan block and a half; its vaults are 37 meters in height, higher than a modern ten-story building; its southern, Romanesque tower is 107.5 meters tall, and the northern, Jehan de Beauce tower, 114 meters – a 30-storey skyscraper of "hewn rock ... hoisted into heaven."

We don't know much about the people who "climbed on sketchy ladders" to build the Chartres Cathedral. We know that the Cathedral was founded on the site of an ancient temple and an early medieval church. We think that its construction in its current form commenced in 1145, stopped and then resumed after a fire in 1194. We know that it was completed in the early part of the thirteenth century – very rapidly in medieval terms – but very little beyond that.

This is not just an unfortunate gap in our historical knowledge; it is an integral part of the story of the Chartres Cathedral in particular and the Gothic cathedral in general. The cathedral has no architect. Its construction has no exact beginning or end, and no blueprint for it to follow. It is an achievement of many hands – a grand achievement, and all the more human for it. This is also true of science, and is the main reason we have started the book with the cathedral: it will serve us as an ongoing metaphor with which to think about the coming-into-being of science.

Figure 1.1 Chartres Cathedral, southern façade. The bridge-like structures between the Romanesque tower and the transept (marked by the rose window) and around the rear on the eastern side are the 'flying buttresses' supporting the walls.

We need such a guiding metaphor as it is difficult to see, at first sight, what a history of science might be. We commonly use 'science' to mean the correct and proper way in which we know how the world is and works; so in what sense does science have a history? We may think of such a history as a list of all the ways our predecessors used to get it wrong until we got it right, but little insight into our predecessors' ways of attaining knowledge – and our own indebtedness to these ways – can be gained by such an approach. And even if we took this approach as an idle but innocent curiosity, it is completely unclear where such a list should start and where it should end. Why should we bother about any mistake and superstition more than any other?

The English word 'science' comes from the Latin *scientia*: 'true and well-supported knowledge.' But *scientia* is science's ideal. In reality, science is a cathedral: it is an achievement – grand, yet *human*. Like all human knowledge, like all beliefs and ways of developing and supporting them, science is particular, local and historical.

Philosophy: The Cathedral that is Science

It *is* difficult to think of science as having a history. It is obvious that people in earlier epochs knew the world differently than we do. But since we are rightly impressed by our own knowledge of the world – by our science – it is very tempting to assume that they were simply wrong, and that science's past consists of a march towards its present. In other words, it seems as if the reason for *our* beliefs lies in their truth. It seems that if we gather and produce knowledge the way we do, it is simply because these are the proper methods to do so. It seems that if we support our knowledge by the evidence and arguments we use, it is because these are reliable evidence and valid arguments. And it seems that if people of yore thought otherwise, it is because they didn't yet know what we already do.

This is a tempting thought, but an entirely misleading one. It puts the cart before the horse: we think the way we do because we followed a route laid down by our predecessors. We think that bodies have 'mass' because Isaac Newton needed to explain to himself and to his rivals how bodies attract one another. We no longer think of matter or mass the way Newton thought – he didn't 'get it right.' But we still use his concept and his mathematics – had Newton lost some of his debates, which might very well have happened, we would have had a different physics. We have the 'unconscious' because Sigmund Freud was intrigued and fascinated by women who were blind despite healthy eyes or paralyzed despite healthy limbs. But we no longer have hysteria, the malady that Freud explained psychologically; Freud didn't discover for us something we now know to be true. Yet 'unconscious' is still as integral a part of psychology as it is of general culture. Had there not been Freud, we would have had a different psychology.

This is what it means for science to have a history. It means that we are not the aim and final cause of the work of people of the past. Rather, we are the product of their work. Our thoughts and beliefs are not the correction of their mistakes but the outcome of their struggles with the challenges that *they* faced, in *their* time, with the resources available to *them*. Had they come up with different ways to accommodate those challenges, we would have different beliefs. We rightly hold our beliefs as true, but they are true because of the effort put into making them so. Their truth is not the cause of this effort but its outcome.

This is a difficult insight – that our knowledge is truly contingent, determined by its history, like every other human affair. Thinking about cathedrals makes this idea easier to come to terms with. Here is an example.

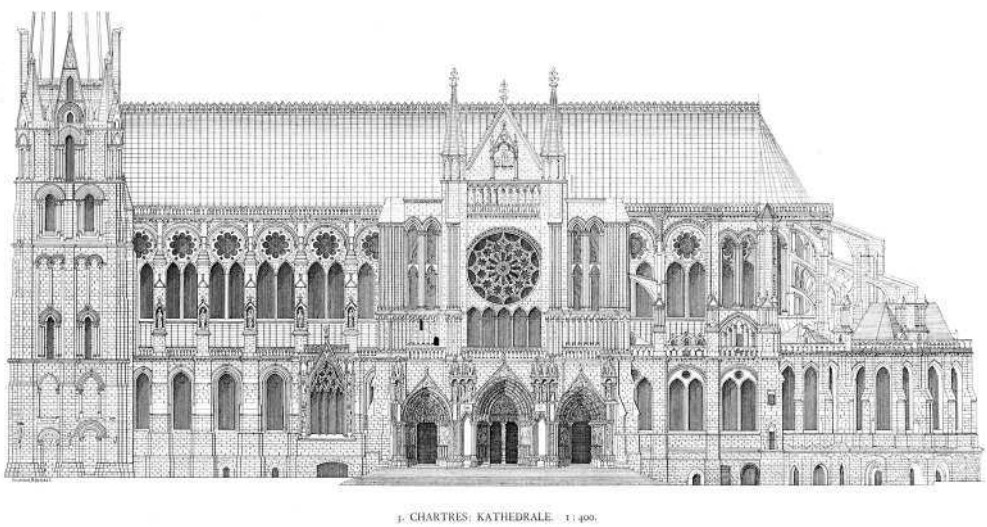

Figure 1.2 The Dream of Harmony: a modern, scaled diagram of the south elevation of the Chartres Cathedral, from G. Dehio and G. von Bezold, *Die Kirchliche Baukunst des abendlandes* (Stuttgart: Cotta, 1887–1902).

Observed with an admiring eye, the Gothic cathedral looks like the marvel of order and harmony represented in Figure 1.2. The cathedral does reflect a very particular, strict idea of order: it aspires to be a cross whose parts relate to each other in musical proportions (more on this below). But even a casual examination of the actual building, rather than its idealized drawings, reveals that it falls far short of this ideal. Look at Figure 1.3 and you'll note the uneven spires, the differently sized windows and, in general, the asymmetry and inconsistency. Yet these imperfections should not be looked down upon. They are marks of a living, evolving human undertaking: fire or earthquake damage repaired; a new spire erected; balustrades and cornices added or remodeled; a pipe organ installed or removed. Moreover: the cathedral doesn't have to be, and never is, complete. Perfect order may be the proper representation of the worshipped God, but it is not required for actual worship: ancient chapels can be used while the grandiose nave is under construction; a wooden roof can be installed if a proper dome isn't affordable. Like any human artifact, especially one created over centuries, the cathedral carries all the marks of the changing opportunities, resources and aspirations of the many people building it, as well as the difficulties which faced them and their imperfect solutions.

This is not to say that the cathedral does not embody ideals of order, perfection and harmony. Quite the opposite: these were exactly the ideals of the people who "climbed on sketchy ladders towards God." But it is this very

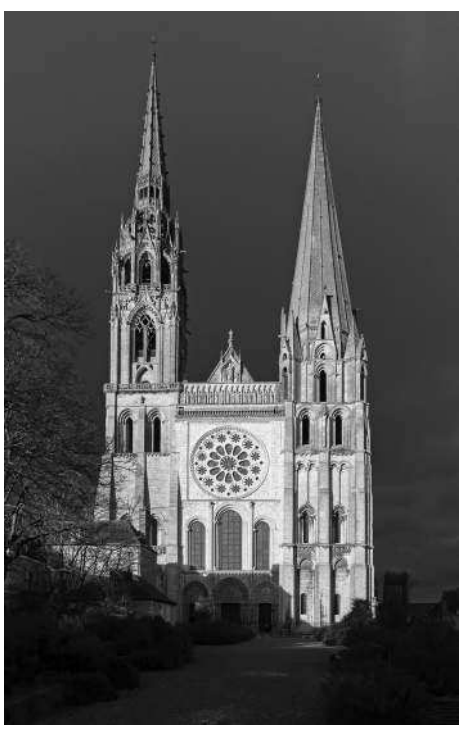

Figure 1.3 The Asymmetrical Reality: the Chartres Cathedral's façade. Note that while the center – built more or less continuously – is properly symmetrical, the two towers, and especially the spires – built some four centuries apart – are growingly asymmetrical.

point that needs to be stressed: harmonious order was an ideal to which the people building the cathedral subscribed, not a template they could follow. This is the way we need to think about science. We know that the claims of our science are 'true,' but this truth is an ideal which guides science. It is not some *thing*, existing prior to and independently of the inquiry, waiting to be revealed. When evidence and argument convince scientists that some claim is true, it does not mean that they have reached something that was always there, obscured by error and misjudgment. It definitely does not mean that this 'something' will always be there. What it does mean is that they have succeeded in using their resources to solve a current challenge in a way that they find satisfactory, even though they are most likely well aware that this solution is temporary, and so is the challenge. Like the building of the cathedral, scientific work has moments of satisfaction, even glory, but is never completed. And like harmony for the building of the cathedral, truth is an ideal that guides scientific research; like the cathedral, science is the product of people striving towards this ideal, not its accomplishment.

Yet another reason to turn to the cathedral as a metaphor for science is that like the cathedral, and like most human accomplishments, science is a work of many hands (Figure 1.4). It has no single architect, no single design, no single vision it follows. It is forgivable that we concentrate, in this book and in the historiography of science in general, on the exciting contributions of great thinkers such as Aristotle, Galileo and Newton. But great contributions should not be construed as great leaps forward. In science, as in the building of the cathedral, all hands are necessary and every "winch and pulley" is indispensable. Of course, some craftspeople are more skilled than others, and some crafts are more difficult to acquire and replicate. But at no point can the master mason completely transcend the work

Figure 1.4 Work of many hands: Jean Fouquet's *The Construction of the Temple of Jerusalem by King Solomon* (c. 1475) – a miniature illustration from a manuscript edition of Josephus Flavius' *The Antiquities of the Jews* (man. fr. 247, fol. 163 v. BN, Paris. Josephus' text is from c. 94). Fouquet depicts the king visiting what he imagines as a construction site of a cathedral (modeled on the Notre Dame in Paris), populated by a swarm of workers engaged in different facets of the construction, requiring different tools and expertise.

of the youngest and least experienced stone-chipper; it is always the "hewn rock" produced by one that the other has to use. A Copernicus or a Kepler may construct a new way to look at the astronomical relations between Heaven and Earth, but he can only do so using the available intellectual resources developed by the astronomers, mathematicians and natural philosophers of his and earlier generations.

The way in which knowledge is rooted in a particular time and place is yet another philosophical insight about science and its history that the cathedral metaphor illustrates. Science is the most global of all modern-day endeavors: laboratories and computer programs, theories and empirical procedures, are fundamentally the same in the United States and China, in Australia and Sweden. We tend to assume that this globality means that scientific knowledge is in its very essence *universal*. We are commonly told that by developing a 'scientific method,' allegedly independent of time and place, we are now discovering 'scientific truths' that are independent of time and place. Looking at the cathedral, we can once again see that this assumption of universality confuses historical cause and effect.

Like science, one finds Gothic cathedrals all over the globe: they dot Central and Western Europe, there are many in Asia, and especially South America. There is even one, built using traditional materials and techniques, on West 110 St., New York. Yet no one would suggest that there is something inherently universal about cathedrals. We can easily see that they originated in a certain place and at a certain time, taking their shape for the religious, aesthetic and practical reasons in play there and then (we will consider these briefly below). The reasons why they are to be found in this distinctive shape in so many places and so far away from their origins are different. The global presence of Gothic cathedrals no longer relates to the preferences of the people who originally shaped them in the independent communities of small and enclosed Europe, but to what these cathedrals came to symbolize in the political and religious circumstances of empire and mission, two, three and four centuries later. The globality of the Gothic cathedral has little to do with what actually makes it a Gothic cathedral.

Similarly, the globality of scientific theories and procedures is *not* a sign of an inherent universality; not any more than the globality of the Gothic cathedral is a sign of an inherent universality of the pointed arch or the flying buttress (see Figure 1.1). The universal aspirations of scientists are important for understanding the global reach of their work, and the religious aspirations of those who "took up God's house to meet him" are important for understanding why they built similar cathedrals around the

globe. But the point is that science and cathedrals are everywhere because they were *exported*. The universality of science is the *outcome* of its history, not its cause. This is what it means for science to have a history.

Science has a history because it's a unique human cultural phenomenon. It is the unique – indeed diverse and incoherent – cluster of beliefs and practices being taught, exercised and sanctioned by the relevant social institutions of today: universities, governmental research institutes, scientific journals. But just as the global presence of science doesn't imply that scientific knowledge is inherently universal – that its claims and procedures are independent of the places and times where they are produced and implemented – the unique character of science doesn't imply that scientific knowledge has a unique access to truth or a unique hold on rationality.

This claim is in no sense a retreat from the point stressed above: that science is a marvelous achievement. It is just a reminder that it is a human achievement, and as such its accomplishments can only be measured against the challenges it was set to meet by the people who set them. There were and there are many other such clusters of beliefs, techniques, tools and institutions; such 'systems of knowledge,' complex and rich in their own right, fulfilling a crucial role in their own cultures, satisfying the curiosity and practical needs of their practitioners. As on-lookers from our own culture of science, we may find some of them particularly admirable and recognize that they comprise capacities that science doesn't provide: Polynesian seafaring and navigation techniques; ancient Chinese medicine; Australian Aboriginal fire technology; Inca astronomy; and certainly many more.

But none of these types of knowledge is 'science.' To say that science has a history means that we don't use this term as an honorific title. We don't bestow it to label types of knowledge that impress us or that we believe in, nor deny it from those we don't approve of. 'Science' is a proper name – the name by which we call those things taught and exercised in contemporary science faculties. It is the history of these beliefs, practices and institutions that we will follow below, and we will touch upon other beliefs and practices only if they have crossed paths with that particular history, as resources, competition, context or alternative for science-to-be.

History: The Cathedral as a Turning Point

The cathedral helps us understand what it means for science to have a history, and it's also a good place to start telling this history. This is because science's history, like all histories, has no clear beginning but many interesting turning points, and the great Gothic cathedral represents one of

them. It was in the time of the cathedral – the era in which Chartres was built (see above), 'the High Middle Ages'[1] – and often inside and around the cathedral, that many of the modes, practices and institutions of science began to emerge.

The time of the grand cathedral is pivotal in the emergence of science, first, because it is a moment in European history when building a cathedral has become materially and socially feasible. The commitment towards such an undertaking – as science would also become – is extreme. It takes resources, which in agrarian communities are always scarce, and divests them into a very expensive project that takes not only years but generations to complete, and which would not contribute to the material welfare of the community even in the long run. The communities in urban centers like Paris, Cologne, Florence and Barcelona, but also in more rural areas like Noyon, Soisson and of course Chartres were strong, affluent and independent enough to undertake such a venture. The reasons are many and complex, but some of them are directly relevant to us: they have to do with knowledge. New technologies – wind and water mills, looms and deep ploughs (which we will discuss below) – significantly improved the economic conditions of European peasants and burghers, and brought with them dramatic social changes. The ambitious project that science would develop into could not have been imagined before these changes.

The age of the Gothic cathedral is also the culmination of an era in which the central and unifying force in Europe, culturally and politically, was an institution whose core was *intellectual*: the Catholic Church. The medieval Catholic Church drew its legitimacy and claim to power from the erudition of its leaders and the knowledge – mainly divine but also profane – which its emissaries garnered and imparted as priests, scholars and educators. The Church of this era represents a unique bridge between the political and the learned and between the mundane and the abstract that was essential to the coming to being of science and the intellectual and institutional form it would take. One of the expressions of this bridge is the establishment of the institution of research and teaching most identified with science from its inception until today: the university. Fundamentally religious, many of the early universities found their first homes in cathedrals.

[1] 'Middle Ages' and 'Dark Ages,' as will be discussed in Chapter 5, are titles coined in hindsight, by scholars of the fourteenth and fifteenth centuries. They used them to refer to the previous thousand years, stretching from the final collapse of the Roman Empire in the fifth century to their own era, which they called 'Renaissance' – rebirth. These terms demonstrate the problems with historians' categories: people living through this millennium obviously didn't experience their life and times as being just 'in between.' For them, these were by far the most important times.

Finally, the age of the cathedral also witnessed the appropriation into Christian learning of the great achievements of Greek thought (originating from the realm of Hellenistic[2] culture and originally written in Greek): metaphysics, astronomy, logic, cosmology, philosophy of nature, medicine, mathematics. If one has to choose a starting point for the history of modern science from the simple perspective of content, Greek knowledge is definitely the most obvious choice. But beyond content, the importation of the Greek corpus into Christian Europe is also a mark of the uniqueness of the cultural-historical moment represented by the Gothic cathedral. The European search for this knowledge was driven by the new universities' urge to acquire teaching material. The knowledge – in the form of manuscripts in Greek and Arabic – was available because of the gradual collapse of the Byzantine Empire and because of the shoulder-rubbing with the thriving Muslim culture in the west, south and east. And because of these cross-cultural sources, the quest for Greek knowledge set in motion a translation project unlike any in history.

Historiography: Culture and Knowledge

Finally, the cathedral is a synecdoche[3] of high medieval knowledge, and looking at it we can ask: what kind of knowledge does it take to build a cathedral? What knowledge of the world does the cathedral reflect? And more generally: what does it take to tell a history of knowledge? What kind of history is it?

One can start by asking the most straightforward type of question: how did the builders of the cathedral move such a grand amount of stone – some 80,000 tons for a large cathedral – from its place of quarry to the building site, which could be many miles away?

This is a simple question, and the short answer also seems simple: with horses. In fact, this answer turns out to be rich and complex.

The decline of horseback warfare in Europe in the second half of the Middle Ages[4] made draft horses cheaper and available to agriculture. Originally bred to carry heavily armored knights as well as their own armor, they were big, strong and agile, so they could operate a new kind of agricultural technology: the heavy plough (Figure 1.5, right). Replacing the shallow scratching of the traditional plough (Figure 1.5, left), the heavy plough dug deep into the ground and turned the soil, eliminating the need to let the soil

[2] Throughout the book I'll use 'Hellenic' to refer to the ethnically Greek and their indigenous realm and 'Hellenistic' to their culture as it spread beyond that.
[3] 'Synecdoche' means 'in a nutshell'; a part or a detail that represents the whole.
[4] Wars were obviously still abundant, but the knights seem to have noticed that they were being most un-chivalrously massacred by longbow-holding peasants on foot.