Margarida Tavares da Conceição

University of Coimbra-Centre
for Social Studies
Colégio de S. Jerónimo
3001-401 Coimbra
mmtc@netcabo.pt

Keywords: Pedro Nunes,
architectural theory, history of
science, architectural treatises,
cosmography, surveying,
Vitruvius, sphere, sundial,
navigation, geodesy, rhumb line,
loxodrome

Research

Translating Vitruvius and Measuring the Sky: On Pedro Nunes and Architecture

Abstract. Pedro Nunes is usually associated with the theory of classicist architecture in Portugal, mostly as a result of his declared intention to translate Vitruvius, but over the course of his long career other important theoretical connections between his mathematical procedures and architectural knowledge emerged as well. Although he was famous as a scholar and tutor of princes, his work as a cosmographer shows his indirect contribution to architectural knowledge. More specifically, his teachings on the sphere and use of surveying instruments for measuring spatial coordinates in navigation provide important indications of the link with architecture. These aspects are also demonstrated in his scientific works, such as the *Treatise on the Sphere* and the *Book of Algebra in Geometry and Arithmetic*. Though doubts persist as to his direct relationship with the Vitruvian tradition, there is evidence of knowledge shared between the disciplines, particularly the use of the sundial or nautical needle for orientation and the organization of space.

Scholar and cosmographer

Pedro Nunes (1502-1578) was undoubtedly the most famous Portuguese figure in the history of mathematics, with international influence in his day. He has now become the subject of new research, which has already provided a more solid understanding of his work;¹ indeed, his career and institutional affiliations are important for our appreciation of Portuguese architectural knowledge in the sixteenth century. However, we should perhaps begin by examining his personal background, as mathematics was for him more of a vocation than a profession. In fact, he was responsible for the first usage of the Portuguese word *matemática*, both as a noun ('mathematics') and adjective ('mathematical'), and also, significantly, in the plural (*matemáticas*) in the sense of *artes matemáticas* ('mathematical arts'). This referred to a disciplinary area that was still in formation, a cluster of practical activities united by common bases in geometry and arithmetic, but which did not lead to a profession or to a clearly-defined professional status.²

Thus, in labelling Pedro Nunes a mathematician, we are implicitly acknowledging his various professional functions, often exercised simultaneously. His career took place largely within the ambit of the university, but he was also a high-ranking official of the Crown. He may have been born into a Jewish or New Christian family, given the long mathematical tradition amongst Iberian Jews; however, the first documented mention of him occurs with regards to his university training. He studied at the University of Salamanca (1526), but was already in Lisbon when he was appointed royal cosmographer and professor at the Portuguese University, then called '*Estudos Gerais*' (1529).³ His career really took off when the University was transferred from Lisbon to Coimbra during the reforms launched by King João III in 1537. He was officially appointed

professor in 1544, responsible for the chair in mathematics, which had at the same time been established within the course of Medicine, and which now became an autonomous discipline for the first time. He remained responsible for the subject until 1562, the year of his retirement.

As can be seen from this brief summary of his career, he was definitively associated with the university milieu. However, he was also engaged in another kind of high-level teaching, namely the tutoring of princes. In fact, it has been suggested [Leitão 2003: 65] that his professional career may have begun as court mathematician, teaching the king's younger brothers.⁴ If so, this would explain his appointment as royal cosmographer and university professor. Indeed, some of what we know about this parallel activity is gleaned from Nunes himself, and is also confirmed by other sources, although in all cases the detail is scanty.

Pedro Nunes's allusions to the scientific aptitudes of some of his disciples shows that reference was already being made to the classical treatises of Antiquity (whether Euclid or Aristotle) in connection with matters related to cosmography, through experimentation with prototypes of navigational instruments. However, it is difficult to generalise on this matter. This is because, given Pedro Nunes's position as royal cosmographer and the physical proximity between the warehouses of India and the royal palace, it is also possible (indeed probable) that there were subsequent contacts with members of the court. This means that it is sometimes difficult to clearly distinguish the position of master from another type of relationship that may have been pedagogical or scientific in nature, such as discussions or informal lessons, which may not be restricted to members of the royal family but extended to young noblemen (*moços fidalgos*).

The likelihood of this has nourished the notion that Pedro Nunes may have taught more extensively at the palace [Moreira 1982, 1998] and that he may even have been tutor to King Sebastião. While this is undocumented institutionally, there is little to contradict it informally, though such lessons would have been open to a very restricted group of people.⁵ On the other hand, we should bear in mind that there were other mathematics masters connected to the royal palace who also left behind influential works. These include Domingos Peres,⁶ and particularly D. Francisco de Melo,⁷ who had an in-depth knowledge of the theoretical sources of architecture.

It is therefore also significant that Pedro Nunes appears to have had a third strand to his teaching activities, for, in addition to his positions as palace tutor and university professor, he also seems to have been engaged in nautical training. In 1529, he was appointed royal cosmographer, becoming chief royal cosmographer in 1547, the first person to occupy this post; indeed, he may have been responsible for drawing up the first regulations concerning it (1559).⁸ It appears that particular importance was given to the need for aptitude tests for the manufacturers of nautical instruments, cartographers and seafarers (particularly pilots and captains), and that such tests were necessary for professional accreditation. Thus, the head cosmographer was obliged to give daily mathematics lessons (*lição de mathematica*) to the seamen, though these were apparently not compulsory and were also open to "noblemen" (meaning that they were effectively public lectures). It is not clear how they functioned or for how long, but after 1594 they also became compulsory for architecture apprentices [Conceição 2008: 201-205, 396-401].

Although we do not know if the regulations governing the post were actually applied, it is not difficult to discover the kind of mathematics that was taught in those lessons; the

text itself details the materials to be read [Mota 1969: 32-33], and all are related to elementary cosmography and the correct use of navigational instruments. It appears that the lessons involved instruction in the observation of astronomical data through the handling of instruments, and some calculations; that is to say, the emphasis was on practical procedures, such as the use of nautical charts, the astrolabe, cross-staff and quadrant, compass and gnomon. The subjects listed are basic and operational, and do not even include the principles of geometry. Moreover, while the regulations also make provision for the reading of the *Tratado da Sphera* (*Treatise on the Sphere*), this was only for the brighter students, as it was considered to be more advanced knowledge in this context (indeed, it forms the basis of theoretical knowledge in this matter). The information given about exam questions also confirms this focus on practical knowledge and technical procedure; the cumulation of practical experience was much more necessary than theoretical knowledge for the exam, and indeed, experience was the only compulsory condition for admission to it.

While there is no obvious connection with architecture in Pedro Nunes's legacy as scholar and head cosmographer, or indirectly in his professional career, the same cannot be said about the measurement of non-visualizable distances. In fact, it is in the field of surveying (i.e., the measurement of things imperceptible to eye or arm, and the determination of the spatial coordinates of one's location and the place where one is heading) that the measurement of the sphere comes into its own, whatever the scale. And this always involves geometrical procedures; in the case of navigation, the application of the principles of trigonometry. The cosmographer's mathematics lesson was thus concerned with providing a technical apprenticeship in the art of navigation.

We should not, therefore, overlook the possibility of a latent connection between nautical science and architectural practice. The problem, however, is that such a connection (mathematical-geometrical in nature) may only be gauged in the world of practice and materials. If the common denominator is trigonometry, then there is a hiatus on the theoretical level, because the connection is nowhere explained textually. To put it simply, if this connection only existed in practice, that would explain why no direct links with architecture have been found in the career of Pedro Nunes. What appears to exist, though, is a non-explicit connection between nautical science and architecture.

The Tratado da Sphera and the Libro de Algebra en Arithmetica y Geometria

Pedro Nunes was essentially a scholar, and it was in this capacity that he produced his theoretical work, most of which is printed. It should be pointed out that this was essentially humanistic scholarship [Tarrió 2002], an aspect that is particularly evident in the philological method that he used to read and translate classical sources. Another feature is his use of various languages; he moves from translations and originals in Portuguese to Latin for international use, and finally, Spanish for a more widespread divulgation of his work.

One of the most interesting aspects revealed by his printed work is the speed with which he apparently gained access to the most recent bibliography of the period. This is related to another important factor, namely his numerous contacts with personalities of international renown (such as Élie Vinet, John Dee, Federico Commandino and Gerardus Mercator, to cite just a few). This obviously operated in reverse, as these circles also acquired knowledge of Nunes's work.⁹ In fact, Pedro Nunes is unrivalled by any other Portuguese figure connected to science as regards the quantity of printed works he

produced.¹⁰ While this is not the place for an exhaustive list, we may note that his whole oeuvre had something in common – a rigorous and clear use of language, structured around the mathematical discourse and vocabulary of Euclid (i.e., proposition, demonstration and corollary), complemented by the use of drawn figures.

Let us begin by looking at Pedro Nunes's first printed work, the *Tratado da Sphera*¹¹ [Nunes 2002], an abbreviated title for what was in fact a volume containing five different works. The core of the book is a (partial) translation of three works essential to cosmography. It begins with the most widely-known medieval manual, *Sphaera Mundi* by Johannes de Sacrobosco (John Holywood), which is followed by a translation of the first chapters of *Theoricae novae planetarum* (Nuremberg, 1472, Princeps edition) by Georg Purbach, and the first book of Ptolemy's *Geography*. These three translations were the first to be printed in the Portuguese language.

The first observation to be made is that, rather than a mathematics manual, this is a book of cosmography. It is a collection of texts “for beginners”, as Nunes himself acknowledges, suggesting that it had perhaps been compiled at the request of the King; indeed, the three translations are together dedicated to Prince Luís. It was a compendium of basic texts used for teaching at court, although it should be noted that Pedro Nunes did not limit himself to translation and commentary, but also included mathematical demonstrations; nor did he hold back from criticising the classics, while nevertheless acknowledging their essential contributions to the discipline.

The second observation is the most important: this work presents the fundamental theoretical principles for an understanding of the nature of representation of space. As regards Ptolemy's differentiation between geography (the description of the world as a unit) and chorography (the description of particular places), it is clear what differentiates them: the first is quantitative and the second qualitative; one requires measurement and “the institution of mathematics”, while the other involves “the painting of places”.¹² It is clear that the “painting” or description of places did not interest Pedro Nunes, and that he used it merely as a term of comparison. But this is important to distinguish the nature of the methodological support for each approach: “painting” is here synonymous with representation through drawing of a scene that is in view, perceptible to sight and therefore a kind of sensory knowledge; rigorous geographic representation, on the other hand, requires geometric demonstration and the use of the appropriate instruments. But geographical surveying, and the kind of knowledge of the earth acquired through observation of the heavens, require what we today call geographic coordinates, i.e. a means of knowing where a point or place is located without directly observing it, in order for it to be represented in another operation.

This leads directly to the heart of the problem of representation of space, cartographic demarcation and the mathematical abstraction that this implies. The title of Chapter XXI, “On the things that need to be retained when describing the orb on a plane surface”,¹³ makes clear the nature of the cartographer/cosmographer's problem. It is essentially the same problem faced by architects and/or topographic engineers, namely understanding and representing spaces, buildings and machines already existing and (above all) to be planned. The process of architectural and engineering design requires abstract codified graphic representation and the ability to predict, plan and calculate (in all senses of the word) a structure as a result of and in response to a problem, need or force.

This matter of cartographic representation is continued in two small treatises by Nunes himself, which follow the three translations: *Treatise... on some Navigational Doubts* and *Treatise... Defending the Sea Chart: with the regulation of height* (in [Nunes 2002]).¹⁴ These constitute his original innovative contribution to the body of scientific writings on navigation and include important information about the problem of representing spherical bodies on a plane surface. Each of these two texts (but particularly the second) is part of a quest to find the most accurate method of drawing maps to aid navigation.

His controversies with the seamen, more cited than known in detail, are reflected here. In several passages, Pedro Nunes criticises the pilots' scanty knowledge and lack of cartographic skill. The crux of the matter seems to have been their intellectual limitations and inability to process abstract thought. The mathematician's discursive clarity is evident both textually and graphically, with geometric demonstrations of the rhumb line and the reason for preferring great circles in navigation. In fact, it is here that he expounds his "discovery" of the rhumb line (later known as the loxodrome): that which "is not a circle nor a straight line" but "rather a curved irregular line" (fig. 1), explaining the reasons why, in practice, "sailors rarely get it right".¹⁵

Fig. 1. Graphic representation of the so-called "rhumb line" or "loxodrome", from the *Tratado da Sphera* [Nunes 2002: 113]

Despite his criticism of sailors, Nunes was nevertheless very aware of the radical innovations involved in the Portuguese discoveries, "which were not achieved by trial and error, but by our highly-trained seamen equipped with instruments and rules of astrology and geometry".¹⁶ In fact, it is clear from his discourse that his overriding concern was with the rigour of that knowledge, for successful navigation depended upon it.

Basic learning is again the subject of his last printed book,¹⁷ the *Libro de algebra en arithmetica y geometria...* [Nunes 1950], which is the most interesting for architecture and fortification. It is presented as the last in a series of publications of original works by Pedro Nunes, and takes up an important aspect of his first book of 1537, namely education. The use of the Spanish language indicates that this was a work of divulgation, clearly aimed at a much more extensive public than the university scholar. It is effectively

a book for self-study, starting with simple matters and increasing in complexity, and is not restricted to a compilation of basic rules; indeed, it goes into the matter in some depth, by applying the principle of algebra to arithmetic and geometry.

The introductory pages explain that the book is based upon a text initially written in Portuguese some thirty years before, which circulated in manuscript form. Nunes was now obliged to revise and extend the work, updating it to take account of more recent publications, such as those by Girolamo Cardano (1501-1576) and Niccolò Fontana, known as Tartaglia (c. 1500-1557), who were embroiled in a polemic. In fact, his criticisms were mainly directed at Tartaglia's *Quesiti et inventioni diverse* and Cardano's *Practica arithmeticae et mensurandi singularis* (Milan, 1539) and *Ars Magna (Artis Magnae, sive de regulis algebraicis...*, Nuremberg, 1545), although Luca Pacioli (1445-1517) also comes under fire.

Tartaglia undertook the first translation of Euclid's *Elements* (Venice, 1545) and also of Archimedes' work (Venice, 1543), but his work was especially relevant to military architecture. He had already published a work on fortification, *La nuova scientia* (1537, re-edited in 1550), a text in the form of a dialogue, which mixes allegory and mathematics, but which nevertheless constituted the first systematic approach to ballistics as a basis for the planning of fortifications. It was his book *Quesiti et inventioni diverse*, first published in Venice in 1546, and re-edited with additions in 1554, that was the most cited and criticised by Pedro Nunes, along with the *General trattato di numeri et misure* [1556]. The fact that Tartaglia's work was known and studied in Portugal is naturally very important for the theory (and possibly also for the practice) of fortification in the Portuguese context. However, Pedro Nunes's references to it are strictly mathematical, and it is not possible to speculate about the extent to which Tartaglia's work was studied in Portugal or its implications for military engineering prior to the seventeenth century.¹⁸

Both Joaquim de Carvalho and Henrique Leitão, in various works, mention that the *Book of Algebra...* circulated widely, partly due to its influence on the Jesuit, Christoph Clavius. In this work, Nunes demonstrates that he belongs to the restricted number of early mathematicians who truly made use of the principle of algebra, that is, using the notion of the unknown variable (*cosa ignota*) to find a solution to problems that could not be solved through arithmetic or geometry (see "Notas e comentários" to the *Libro de Algebra* by Victor Hugo Duarte de Lemos in [Nunes 1950: 469-498]). It should also be pointed out that, within the Europe-wide chain of transmission of scientific knowledge, Nunes's algebra was in turn analysed and criticised by the Flemish mathematician and military engineer, Simon Stevin (another important name in the development of the military treatise, and pioneer of the Dutch School, whose influence seems to have arrived in Portugal in the first half of the seventeenth century).¹⁹

It is important to highlight this less obvious aspect of the reception and contraposition of ideas, which used the comparison of data as an intrinsic and indispensable part of scientific progress. Indeed, such criticism seems to be part and parcel of the mathematical mentality (demonstration), while scientific proof is intrinsically mathematical in nature, implying, in general terms, a method. When Pedro Nunes granted a "scientific place" to Architecture,²⁰ he was awarding it membership status in accordance with the application of a method: that of the mathematical sciences.

It should also be pointed out that, alongside Euclid, the work of Archimedes was also fundamental for physics and mechanics. In this sense, we understand how the structure

of the treatise, which is divided into three main parts, makes it accessible to non-specialists, presenting information in an organized methodical sequence. The basic definitions are given first, with the statement of rules and respective demonstrations, while the second part deals with the application of those rules to arithmetical operations, roots and “proportions”. The third part deals with equations applied to cases of arithmetic, and (more importantly for engineering) to cases of geometry, presenting sequentially the square, rectangles, triangles, rhombuses, trapeziums, pentagons “and other many-sided shapes”. If we compare this with Book VI of Tartaglia’s *Quesiti e inventioni diverse*, we can see the advance that had been made with the possibility of solving cubic equations (by definition, equations that resolve three-dimensional spatial problems, i.e., geometric).

In addition to the effectiveness of the operations involved in the calculation and planning of defensive structures, intellectual training in mathematics would itself influence the disciplinary contours of fortification, in that similar methods were used, whatever the scale of the object under study (including the city and the territory). In general terms, this was Pedro Nunes’s great indirect contribution to the science/art of military architecture and indeed to architecture as a whole. It was a literally magisterial contribution, made in his capacity as teacher (*magister*). The very concept of science as knowledge supported by and derived from mathematical demonstration – a consideration that connects all his writing and is often made explicit in his discourse [Leitão 2002b: 56-58] – soon became an integral part of architectural training, particularly for military engineering and fortification. This meant that there was now a theoretical component of some kind.

Translating Vitruvius and other attempts

Pedro Nunes’s theoretical output was not limited to his printed works, but also extended to various manuscripts (at least one extant, some attributed and others now disappeared).²¹ One of those lost is obviously of fundamental importance for the theory of architecture: the translation of Vitruvius. Indeed, it is as interpreter of Vitruvius that Pedro Nunes has occasionally appeared in connection with architecture, though this is ultimately a dead-end, as it comes up against something that does not exist. However, it is worthwhile summarising the information that we have on the subject. We know first-hand from Nunes himself that there was an intention and an action; in the dedication of *De crepusculis* [Nunes 2003], dated October 1541, Nunes mentions that he had worked on the translation and/or commentary of Vitruvius’s treatise *De architectura* at the request of King João III.²²

The importance of this in the cultural context of the 1540s is only demonstrable by comparing it with other attempts to translate essential texts for the theory and history of architecture. The interest in books on architecture may be gauged by the re-publication of *Medidas del Romano* by Diego de Sagredo (ca. 1490-ca. 1528), which was printed in 1526 in Toledo and ran to three editions in Lisbon, between 1541 and 1542.²³ A little later, André de Resende, a humanist close to Erasmus, was ordered by the king to translate a book of architecture, probably Alberti’s *De re aedificatoria* in around 1551 or 1552.²⁴ Prior to this, André de Resende had translated (ca. 1542-1543), “two books about aqueducts”, possibly the *De aquaeductibus urbis romae* by Sexto Júlio Frontino, one of the appendices that accompanied editions of Fra Giocondo [Moreira 1983: 42; Moreira 1991: 351-352; Moreira 1995a: 346; Deswarte, 1992: 171]. There is also indirect evidence of another translation, the book about the fortification of cities by

Albrecht Dürer [1527], which may have been translated into Portuguese in 1552 by Isidoro de Almeida [Moreira 1983: 343], a soldier with some vocation for architectural design.

If Pedro Nunes's translation of Vitruvius actually existed (in 1541-1542) and was printed, it would have been the first vernacular version outside Italy²⁵ [Moreira 1998: 385]. But was it ever finished? Joaquim de Carvalho, noting the meaning of specific terms used by Pedro Nunes, suggests that a translation with critical explanations did exist (the word *interpretatio* recurs), though he doubts that the task was concluded (see [Nunes 2003: 315-317]). However, Henrique Leitão [2002 b: 45] points out that Nunes mentions Vitruvius on certain occasions, though always within the context of the scientific themes covered in Book IX of *De architectura*, and argues that there is sufficient evidence to assert that the text existed and, like other lost unpublished works, was known outside Portugal [Leitão 2002: 65-66; 2002a: 122]. That is to say, in addition to Pedro Nunes's own words, there is also some evidence elsewhere, ill-defined but nevertheless visible.

The first piece of evidence is more of an indirect proof than an indication. The inventory of the books belonging to the Spanish architect Francisco de Mora mentions "a Lusitanian, Pedro Nuñez, of architecture and navigation",²⁶ which would certainly be a reference to Nunes's translation of Vitruvius and to some text about nautical science. A second clue, also cited by Henrique Leitão [2002a: 122] after Rafael Moreira [1995b: 51], is the fact that the humanist Walther Hermann Ryff (ca. 1500-ca. 1548), who undertook the first German translation of *De architectura libri decem* (known as the *Vitruvius Teustsh*, Nuremberg, 1548), mentions the name of Pedro Nunes as one of the authorities on the matter.²⁷ Ryff was both a physician and a mathematician, which would combine well with the study of the work of Pedro Nunes or contact with some of his works.

There is yet another clue, uncertain though very interesting. Henrique Leitão mentions an unresolved question concerning Francesco Maurolico (1494-1575), a Sicilian mathematician who, in his *Cosmographia* (1543) on the subject of wind names and directions, cites an opinion that he attributes to Pedro Nunes [Leitão 2002a: 117]. Given the date of that printed reference and the expression used by Nunes with respect to *interpretationem vitruuii*, it is likely to refer to the winds from Book I of *De architectura*, which the Portuguese mathematician was clearly familiar with. Vitruvius's first book is undoubtedly the most far-reaching in cultural and disciplinary terms, and contains the basic definitions; it could not have been unknown to the humanist Pedro Nunes. Moreover, Chapter 6 of that book is entirely dedicated to town planning, and street layout had to take account of wind types, particularly the direction of the eight main winds. This is, in fact, one of Vitruvius's most cited topics in architecture theory due to the matricial induction of the geometric octagon.

On the other hand, even if a translation (partial or otherwise) had existed and circulated, Vitruvius appears to have made no impact whatsoever on the extensive writings of Pedro Nunes. Direct or indirect quotations from him are very scarce, and when they occur, it is only in connection with cosmographic matters.

Moreover, in the chapter of *Tratado da Sphera* concerning the measurements of the sphere [Nunes 2002:14], Pedro Nunes actively suppresses Vitruvius amongst the authorities cited in Sacrobosco's text, referring only to Ambrosius Theodosius Macrobius and Eratosthenes. However, this omission also occurs in some other versions of this

medieval treatise.²⁸ The context of that annotation is the chapter about “the distribution of squares and streets” (i.e., urban layout) and the sentence appears after an explanation of the use of the gnomon and the different directions of streets and winds. This may lead to two interlinked hypotheses: firstly, Pedro Nunes may have avoided mentioning Vitruvius because he considered him irrelevant, on the grounds that he drew his information from Erastosthenes. This would in turn imply that Nunes had read and studied Vitruvius directly and realised that his opinion was not his own but that he was referring to another source.

But, in this volume of *Tratado da Sphera*, there is another explicit reference to Vitruvius in another context. It comes at the beginning of the *Treatise...on Some Navigational Doubts* concerning the explanation of rhumb lines and is worth transcribing:

Because it is clear that: drawing a meridian line on the horizon: by the art that Vitruvius brings to this: that line is called the north-south rhumb line: and crossing this line with another perpendicular to it: we will have the east-west rhumb line: and thus the whole circle of the horizon will be divided into quarters, each of ninety degrees. And this is thus represented by the needle with which we navigate: and also by any of the needles that are painted on the map.²⁹

This sentence by Pedro Nunes is revealing. Rafael Moreira [1995b: 51] believes that the reference to the “art of Vitruvius” alludes to the *analemma*, or structural lines of the horizon, which concerns Chapter 1 of Book IX of *De Architectura*, the book dealing with “knowledge of astronomy and gnomonics”. But this suggestion does not annul the knowledge that Pedro Nunes demonstrates of Chapter 6 of Book I, mentioned above, and the sentence itself reveals his understanding of the Vitruvian principles expressed there.

Pedro Nunes is clearly speaking of cosmography in general terms. This means that the sense is by definition spatial, so much so, in fact, that when he refers to the navigation needle, he compares it to other “needles painted on the map” (the windrose), but which could also be “needles” on the ground, such as the gnomon or sundial. In this specific passage citing the *art* of Vitruvius (and Pedro Nunes does not usually make gratuitous assertions), what is at stake is the general principle of organization of space and the instrumentation used for orientation. This coincides with the principle of territorial division and demarcation that occurs during the founding of a city, a subject that completely occupies Book I, alongside the definition of architecture and its elements.

Moreover, what Pedro Nunes effectively describes is the basic scheme of geometry, the relationship of the perpendicular to the cardinal geographic points. This cross scheme constitutes a kind of common heritage shared, on different scales, by geography and astronomy, and the idea of the city.³⁰ This observation is related to Pedro Nunes on a specific point: the instrumental needs of nautical orientation and, in that sense, the reading that the mathematician could not have avoided making from Book I of Vitruvius’s architecture treatise, which itself constitutes a repository of classical knowledge on this matter up to the first century. The notion that Pedro Nunes was only interested in Vitruvius’s more technical books may confuse or mask the issue. Given the sixteenth-century obsession with architecture and its personification in Vitruvius, it is almost impossible that Pedro Nunes had not read it thoroughly. And from it he retained what interested him, as is natural.

But, even if Pedro Nunes had only retained the scientific aspects of Vitruvius, such as information about gnomonics, this is not clearly reflected in his own texts.³¹ And we should not forget how crucial was the construction of reliable clocks, as Pedro Nunes understood, since a rigorous method of measuring time was required to determine longitude.³² This note is important for the verification of the very meaning and use of gnomonics, transforming the gnomon into the common principle underlying all orientation in time and space (by means of the sun's course, a criterion invested with essentiality). This served not only as the basis of the clock (sundial), but also for marking the geometric centre or navel of the city, which regulated the division of territory and urban layout. Indeed, this principle could be applied whatever kind of habitat was involved.

The measurability of space: the sphere and architecture

The medieval notion of a closed world, where space was a symbolic given, gradually gave way to the concept of an infinite universe, in which space could be measured in an increasingly accurate way. However, this change was only really consolidated in the eighteenth century. Underlying it was the development of new conceptual tools that gave control of the spatial dimension and the abstract representation of reality, concrete or virtual. These were mostly developed in the mathematical disciplines, of which geometry was the touchstone. Thus, the discovery of the sphere of the earth as a space of quantification and measurability provided the context for scientific (or more precisely, pre-scientific) knowledge in the era of the Discoveries, proving decisive for the “opening-up” of the world. It also enabled representation from the point of view of the city and architecture.

It is not by chance that there are unequivocal historical references in the first four decades of the sixteenth century to the appearance of architectural designs, in which it is even possible to identify different genres of representation, such as drawings and urban maps. It may also not be chance that there is not the slightest trace of their material existence in Portuguese archives, throwing doubt upon their use and effective conceptual utility [Rossa 2002: 380-381]. Nor is it by chance that sixteenth-century European culture saw a wave of treatises on surveying and instrument-making. There were some reverberations in Portugal, although these have only really been documented and studied in connection with nautical science (this aspect will not be developed in any detail here). The way that some astronomical instruments could be used for both navigational and geodesic purposes is not unknown to historians of science.

However, this deep-rooted relationship between architecture, town planning and nautical science seems to have taken place on another, less explicit level. Recent data from the research of João Horta [2006] uses mathematical analysis to demonstrate this connection in a way that only becomes operational on a case-by-case, city-by-city or object-by-object basis. In terms of scale, it is as if, from the horizon of the sphere, a microscope were used to see the ground. This is a fundamental question, as it means that mathematical language may be used to reconstruct the planning process using a process of geometrical analytic deconstruction – an aspect of research where traditional historical analysis of theoretical texts on town-planning proves insufficient or inconclusive.

In short, in Horta's work [2006: 79], a direct link is made between the three-dimensional logic of nautical geometry (which is necessarily cosmographic or Sphere-based) and the plane surface geometry of architecture and town planning. The abacus, diagram or grid, used as a tool for town planning and architecture (including naval

architecture), shares a common matrix with the so-called compass rose or wind rose. In other words, an archetypal octagonal generative system was used as a basis for planning because it contains the principle for determining geometric solutions/relations.

Thus, it may be seen how this generative schema coincides with the so-called Vitruvian octagon, which is also deduced from the cardinal points. This clearly shows how classical archetypes and proportional measurement systems may be used to generate variable geometric patterns that are coherent in their common matrix. Also significant is the fact that the same matrix is evoked by Pedro Nunes for the cartographic design of the terrestrial sphere, as mentioned above [Nunes 2002: 106], thereby recovering Vitruvius's legacy, itself an archetypal treatise.

Fig. 2. Cosmographic diagrams based on trigonometry, from the *Tratado da Sphera* [Nunes 2002: 108-109]

To be precise, the instrumental capacity of the windrose diagram is based upon trigonometric principles inherent in the spherical nature of the earthly globe. It effectively constitutes a trigonometric grid that can be adapted to town planning in specific cases (fig. 2). That is to say, the same trigonometric principle, calculated diagrammatically, using an abacus or with a combination of both, is always based upon a double quadrature or octagonal base, whose lines of angular metric coordination may be used on the geographic, urbanistic or architectural scale. This means that it could virtually generate various proportional systems of differing degrees of complexity.

To sum up, João Horta has demonstrated that it is possible to use nautical charts or a simple abacus scheme to design on paper or on the ground in a geometrically coherent way. It was probably not architects or engineers, but rather pilots, foremen and soldiers, people with little sophisticated literary or theoretical knowledge but with elementary

mathematics, who were responsible for navigation, docking and building. More important than the architecture and fortification treatises that circulated during the sixteenth century would have been “the use of calculation tools, like the set square, ruler, compass or design manual, instruments whose worth was already proven and valued, and which circulated unpretentiously. But this labour is never given credit. Perhaps that is why there seems to have been no documental evidence of its use” [Horta 2006: 125].

This almost undocumented effort will also have been related to the need for a representation of the Sphere and with the conception of the universe itself. The development of pre-Cartesian philosophy, still firmly anchored in Aristotelianism, though gradually advancing towards geometric rationality, frames architectural and town planning theory within a broader intellectual process. The principles underlying architecture and town planning, whether expounded in treatises or not, are also related to the mathematization of reality. The ability to measure space and the things in it, describe it textually and represent it cartographically came about not only through experimentation (as a way of validating knowledge) and advances in nautical science, but also, crucially, through the concomitant development of the mathematical sciences, which laid the foundations for the rest.

Translated from the Portuguese by Karen Bennett

Notes

1. The bibliography on Pedro Nunes is very extensive (see [Leitão 2002] for a recent overview). An unfinished project by the Lisbon Academy of Sciences to publish Pedro Nunes’s complete works (begun in 1940 and edited by Joaquim de Carvalho) has recently been resumed with the support of the Calouste Gulbenkian Foundation, with Henrique Leitão as general editor. Since 2002, Volumes I, II, III, IV and VI out of a total of eight planned have been published.
2. This was shown clearly in a recent exhibition and catalogue, *Compass and Rule: Architecture as Mathematical Practice in England* [Gerbino and Johnston 2009].
3. He was later awarded a Doctorate in Medicine (1532) by this institution, although it is not known if he ever actually became a practising “physician”.
4. He certainly taught Prince Luís (1506-1555), Prince Henrique (1512-1580) and Prince Duarte (1515-1540), the last of whom had significant connections with the Ducal court of the Braganças, based in Vila Viçosa. For further information on this, see [Conceição 2008: 196-197].
5. One of those characters was undoubtedly D. João de Castro (1500-1548), Viceroy of India, a multi-faceted figure, whose works reveal an awareness of the importance of Portuguese geographical and cosmographic discoveries in relation to those of the ancients, which he systematically criticises. The same attitude is evident in his familiarity with Vitruvius’s *De architectura* and the comparison he makes with Indian architecture, also considered to be “ancient”. For a more in-depth study of this issue, see [Deswarte 1992: 37-54] and [Moreira 1995b].
6. He left a handwritten version of part of Euclid’s *Elements*, a fragmentary simplified translation meant to be used for elementary teaching purposes. The manuscript was published by Luís de Albuquerque [1968: 121-198].
7. This more complex figure (1490-1536) left original commentaries on texts by Euclid and Archimedes, dating from between 1514 and 1517 [Leitão: 2005: 296; Albuquerque, 1968: 2]. In his inaugural lecture delivered in 1535, he reveals the influence of architecture theorists, citing Vitruvius, though basing himself on an interpretation resulting from Alberti’s *De re aedificatoria* (see *Oração de Sapiência (Oratio pro rostris)*, Miguel Pinto de Meneses, trans., A. Moreira de Sá, ed., Lisbon: Centro de Estudos de História da Filosofia, 1956, pp. 154-157).
8. Here too the extent of his involvement is not known in any detail, and most of our knowledge has been acquired indirectly, via an allusion made to it in the “Regulations concerning the post of Head Cosmographer” (*Regimento do Cosmógrafo-mor*) of 1592. This was published and

- studied by Avelino Teixeira da Mota [1969] and has been taken upon again more recently by Rita Cortez de Matos [1999].
9. A well-documented “dissemination network” existed with regard to the works of Pedro Nunes even while he was alive. It was particularly active in the first decades of the next century, largely due to the Jesuit school of mathematics (see the work of Henrique Leitão, particularly [2002a]).
  10. His printed work included *Tratado da Sphera* (Lisbon, 1537), *Astronomici Introductori de Sphaera Epitome*, (before 1541); *De crepusculis...* (Lisbon, 1542); *De erratis Orontii Finaei...* (Coimbra, 1546; *Petri Nonii Salaciensis Opera...* (Basel, 1566); *Libro de Algebra en Arithmetica y Geometria...* (Antwerp, 1567). Some of the volumes contain different texts, including translations, originals and re-editions, sometimes dedicated to different people.
  11. Published in Lisbon in 1537, the frontispiece read: *Tratado da Sphera com a Theorica do Sol e da Lua. E ho primeiro livro da Geographia de Claudio Ptolomeo Alexãdrino tirados nouamente de latim em lingoagem pello Doutor Pero Nunez cosmographo del Rey dō Ioão he terceyro deste nome nosso Senhor. E acrece[n]tados de muitas annotações e figuras per mays facilmente se podem entender. // Item dous tratados que o mesmo Doutor fez sobre a Carta de marear: Em os quaes se decrarão todas as principaes duuidas da nauegação. Cō as tauoas do mouimento do sol: e sua declinação. E o Regimento da altura assi ao meyo dia: como nos outros tempos.*
  12. ... *pintura dos lugares: e nenhum homem sera Corographo: se não for pintor* ... [Nunes 2002: 64].
  13. *Das cousas que se ham de guardar na descripção do orbe em plano* [Nunes 2002: 89-90].
  14. These two treatises were *Tratado... sobre certas duuidas da nauegação* and *Tratado... em defensam das cartas de marear: com o regimento da altura...*, reprinted in 1566, in a Latin version *De duobus problematis circa nauigandi artem liber unus* and later included in the book *De arte atque ratione nauigandi libri duo*, 1573.
  15. ...*qual não he circulo: nem linha direita ... antes he hua linha curua; e yrregular ...*, *que os nauégantes poucas uezes acertam* [Nunes 2002: 112].
  16. ... *que nam se fizeram indo a acertar: mas partiam os nossos mareantes muy ensinados e prouidos de estormentos e regras de astrologia e geometria: que sam as cousas de que os Cosmographos ham dādar apercebidos* [Nunes 2002: 121].
  17. *Libro de Algebra en Arithmetica y Geometria...*, Antwerp, printed in “*casa de los herderos d’Arnoldo Birkman a la Gallina gorda*” or “*em casa de la Biuda y herederos de Iuan Stelsio*”. The fact that two printers were responsible for different copies of the same edition was a very unusual event, which has not been satisfactorily explained. One of the copies preserved in the National Library of Portugal (BNP, Res. 734 P.) belonged to Luís Serrão Pimentel (1612-1679), head cosmographer and military engineer, who also wrote several treatises.
  18. Pedro Nunes was probably not the only one reading Tartaglia’s books. In any case, the *Quesiti et inventioni diverse* is largely concerned with fortification and military art: artillery (Books I-III); tactics (Book IV); geodetics or land surveying (Book V) and urban fortification (Books V-VII). Of the nine books, only the last three are devoted to purely mathematical subjects.
  19. Simon Stevin, *L’Arithmetique... contenant les computations des nombres Arithmetiques ou vulgaires; Aussi l’algebre, avec les equations de cinc quantitez...* (Leiden, 1585, 1625 and 1634), quoted by Joaquim de Carvalho in his “Anotações histórico-bibliográficas” to the *Libro de Algebra...* in [Nunes 1950: 413-467].
  20. *De todollos Liuros que nas Sciencias Mathematicas tenho composto, muito alto & excellente Principe, nenhum he de tanto proueito como este de Algebra, que he conta fácil & breue para conhecer a quantidade ignota, em qualquer proposito de Arithmetica & Geometria, & em toda a arte que usa de conta & de medida, como sam Cosmographia, Astrologia, Architectura & Mercantil. E posto que os principios desta subtilissima arte sejam tirados dos Liuros elementarios de Euclides, nam se pode porem sem ella ter a practica dos mesmos liuros, & dos de Archimedes* [Nunes 1950: XIII].
  21. The only surviving manuscript is *Defensão do Tratado da Rumação do Globo para a Arte de Navegar*, published by Joaquim de Carvalho [Nunes 1952].

22. ... *sed ut occasionem aliquam nanciscerer excusandi me quod interpretationem Vitruuii tamdiu sim moratus: nam prae aduersa ualeitudine inchoatum opus et supra quam dimidiatum non absolui* [Nunes 2003: 6].
23. The first Lisbon edition was dated June 1541, the second January 1542 and the third June 1542. All were printed by Luís Rodrigues [Moreira 1995a: 344], who also published Pedro Nunes.
24. *Livro de Arquitectura, tradução da Arquitectura de Leão Baptista*. Rafael Moreira suggests that this translation of 1550-1551 had been done from Cosimo Bartoli's Italian version (Florence, 1550 [Moreira 1983: 342]. See [Deswarte 1981: 238; 1988: 333; 1992: 175]; see also [Conceição 2008: 129].
25. Of Vitruvius, the first printed Italian translation was by Cesare Cesariano, 1521; the first printed French translation, by Jean Martin, 1547; the first German translation, by Walther Ryff, 1548; the first printed Spanish translation, by Miguel de Urrea, 1582; see "timeline" in [Conceição 2008].
26. ... *um Pedro nuñez lusitano de architectura y de nabegacion* ... [Leitão 2002a: 122].
27. Prior to the German translation, Ryff had already published the Latin version of *De architectura*, in 1543.
28. Joaquim de Carvalho in [Nunes 2002: 238]. Rafael Moreira [1995b: 51] also refers to this omission and notes that Pedro Nunes may even have highlighted this information source, which is part of Book I, Chapter 6 of *De architectura*.
29. *Porque cousa clara he: que fazendo no horizonte huma linha meridiana: pella arte que Vetruuio pera isso traz: a tal linha se chama o rumo de norte sul: e atravessando linha com outra perpendicular: teremos o rumo de leste oeste: e assi ficara repartido todo o circulo do horizonte em quartas cada huma de nouenta graos. E isto se representa assi pella agulha com que nauegamos: como tambem per qualquer das agulhas que na carta se pintam* [Nunes 2002: 106].
30. This is best demonstrated by *The Idea of a Town* [Rykwert 1988], which identifies a ritualistic-symbolic connection between the form of the city and the religious-transcendent conception of the world. This is encapsulated in the symbol of the cross inside a circle — $\oplus$ — which could be both a cosmological sign, and (in certain pre-Classical and Classical civilizations) an actual ideogram for the word/concept of the city.
31. In *De erratis orontii finaei*..., while opposing the Frenchman's proposals for the construction of the sundial (see Henrique Leitão, "Anotações..." in [Nunes 2005: 318 and 394]), Nunes explains the basic principles of gnomonics in relation to horizontal and vertical sundials. However, there is no reference here to Vitruvius, which suggests he did not give much importance to the cited Book IX.
32. For this reason, the study and use of the sundial is listed in the *Regulations concerning the post of Head Cosmographer* as a subject to be taught to pilots [Mota 1969].

References

- ALBUQUERQUE, Luís de. 1969. *Fragmentos de Euclides numa versão portuguesa do séc. XVI*. Lisbon: Junta de Investigações do Ultramar.
- CONCEIÇÃO, Margarida Tavares da. 2000. A Praça de Guerra, aprendizagens entre a Aula do Paço e a Aula de Fortificação. *Oceanos* 41: 24-38 (Lisbon: Comissão Nacional para as Comemorações dos Descobrimentos Portugueses).
- . 2008. Da cidade e fortificação em textos portugueses (1540-1640). Ph.D. dissertation (Theory and History of Architecture), Faculty of Sciences and Technology, University of Coimbra.
- DESWARTE, Sylvie. 1988. Francisco de Holanda ou le Diable vêtu à l'italienne. Pp. 327-345 in *Les Traités d'Architecture de La Renaissance*, Jean Guillaume, ed. Tours: Picard.
- . 1988. La Rome de D. Miguel da Silva (1515-1525). Pp. 177-307 in *O Humanismo Português, 1500-1600* (Primeiro Simpósio Nacional, Lisbon, 1985). Lisbon: Academia de Ciências de Lisboa.

- . 1992. *Imagens e Ideias na Época dos Descobrimentos, Francisco de Holanda e a Teoria da Arte*. Lisbon: Difel.
- DÜRER, Albrecht. 1527. *Etliche Unterricht zu Befestigung der Stett, Schloz und Flecken*. Nuremberg. (Latin edition, *De urbibus, arcibus, castellisque condendis, ac muniendis rationes...*, Joachim Camerarius, trans. Paris: Christian Wechel, 1535.)
- GERBINO, Anthony and Stephen JOHNSTON. 2009. *Compass & Rule: Architecture as Mathematical Practice in England, 1500-1750*. New Haven – London: Yale University Press - Museum of the History of Science Oxford.
- HORTA, João Manuel Gomes. 2006. Vila Real de Santo António, forma limite no urbanismo histórico português. Ph.D. dissertation, Faculty of Humanities and Social Sciences, University of Algarve.
- LEITÃO, Henrique, ed. 2002. *Pedro Nunes, 1502-1578. Novas terras, novos mares e o que mays he: novo ceo e novas estrelas*. Exhibition catalogue. Lisbon: Biblioteca Nacional.
- . 2002a. Sobre a difusão europeia da obra de Pedro Nunes. *Oceanos* 49: 110-128 (Lisbon: Comissão Nacional para as Comemorações dos Descobrimentos Portugueses).
- . 2002b. Pedro Nunes, leitor de livros antigos e modernos. Pp. 31-58 in *Pedro Nunes e Damião de Góis – Dois Rostos do Humanismo Português, Actas do Colóquio*, Aires Augusto do Nascimento, ed. Lisbon: Guimarães Editores.
- . 2003. Para uma biografia de Pedro Nunes: o surgimento de um matemático, 1502-1542. *Cadernos de Estudos Sefarditas* 3: 45-82 (Lisbon: Universidade de Lisboa).
- , ed. 2004. *O Livro Científico dos Séculos XV e XVI. Ciências Físico-Matemáticas na Biblioteca Nacional*. Lisbon: Biblioteca Nacional.
- MATOS, Rita Cortês de. 1999. O cosmógrafo-mor: o ensino náutico em Portugal nos séculos XVI e XVII. *Oceanos* 38: 55-64 (Lisbon: Comissão Nacional para as Comemorações dos Descobrimentos Portugueses).
- MOREIRA, Rafael. 1998. Um Tratado Português de Architectura do Século XVI (1576 - 1579). *Colectânea de estudos Universo Urbanístico Português 1415-1822*. Lisbon: Comissão Nacional para as Comemorações dos Descobrimentos Portugueses, pp. 353-398.
- . 1983. Architectura. Pp. 305-352 in Catalogue of the XVII Exposição de Arte, Ciência e Cultura, Arte Antiga –I. Lisbon.
- . 1991. A Architectura do Renascimento no Sul de Portugal, a Encomenda Régia entre o Moderno e o Romano. Ph.D. dissertation, Faculty of Humanities and Social Sciences, Universidade Nova de Lisboa.
- . 1995a. Architectura: Renascimento e Classicismo. *História da Arte Portuguesa*, Paulo Pereira, ed. Lisbon: Círculo de Leitores, vol. II, pp. 303-375.
- . 1995b. D. João de Castro e Vitruvius. *As tapeçarias de D. João de Castro*. Exhibition catalogue. Lisbon: Comissão Nacional para as Comemorações dos Descobrimentos Portugueses – IPM, pp. 51-56.
- MOTA, Avelino Teixeira da. 1969. *Os regimentos do cosmógrafo-mor de 1559 e 1592 e as origens do ensino náutico em Portugal*. Lisbon: Junta de Investigações do Ultramar.
- NUNES, Pedro. 1950. *Libro de Algebra en Arithmetica y Geometria* (1567). *Obras*, vol. VI, Joaquim de Carvalho, et al, eds. Lisbon: Academia das Ciências de Lisboa, Imprensa Nacional de Lisboa.
- . 1952. *Defensão do tratado da rumação do globo para a arte de navegar*. Joaquim de Carvalho, ed. Coimbra: *Revista da Universidade de Coimbra* 17.
- . 2002. *Tratado da Sphaera Astronomici Introductorii de Sphaera Epitome* (1537). *Obras*, vol. I, Henrique Leitão, et al., eds. Lisbon: Academia das Ciências de Lisboa, Fundação Calouste Gulbenkian.
- . 2003. *De Crepvsclis* (1542). *Obras*, vol. II, Henrique Leitão, et al., eds. Lisbon: Academia das Ciências de Lisboa, Fundação Calouste Gulbenkian.
- . 2005. *De erratis orontii: finaei regii mathematicarvm lvetiae professoris* (1546). *Obras* vol. III, Henrique Leitão, et al., eds. Lisbon: Academia das Ciências de Lisboa, Fundação Calouste Gulbenkian.

- ROSSA, Walter. 2002. O Urbanismo Regulado e as Primeiras Cidades Coloniais Portuguesas. Pp. 360-389 in: *A Urbe e o Traço. Uma Década de Estudos sobre o Urbanismo Português*. Coimbra: Almedina.
- RYKWERT, Joseph. 1988. *The Idea of a Town*. Cambridge, MA: MIT Press.
- TARRIÓ, Ana Maria. 2002. Pedro Nunes e os Humanistas do seu Tempo. Pp. 59-93 in: *Pedro Nunes e Damião de Góis - Dois Rostos do Humanismo Português*, Actas do Colóquio, Aires Augusto do Nascimento, ed. Lisbon: Guimarães Editores, 2002, pp.
- TARTAGLIA, Nicolo. 1537. *La nuova scientia (Inventione de Nicolo Tartaglia Brisciano intitolata Scientia nouva divisa in 5 libri, nel Primo di quali si dimostra theoricamente la natura & effeti de corpi egualmente graui: in li dui contraij moti che in esse puon accadere: e de lor cotrarij effeti...)*. Venice.
- . 1554. *Quesiti et inventioni diverse de Nicolo Tartaglia. Di novo restampati con una giunta al sesto libro, nella quale si mostra duoi modi di redur una città inespugnabile*. Venice. (Rpt. 1959, Arnaldo Masotti, ed. Brescia: Ateneo di Brescia.)
- . 1556. *La prima [-seconda] parte del General Trattato di Numeri, et Misure di Nicolo Tartaglia, nella quale in diesette libri si dichiara tutti gli atti operativi, pratiche, et regole necessarie... in tutta l' arte negotiaria, & mercantile, ma anchor in ogni altra arte, sciencia, over disciplina, dove intervenghi il calculo...* Venice.
- VITERBO, Francisco Marques de Sousa. 1988. *Dicionário Histórico e Documental dos Arquitectos, Engenheiros e Construtores Portugueses* (1899-1922), 3 vols. Lisbon: Imprensa Nacional - Casa da Moeda.

About the author

Margarida Tavares da Conceição is a historian of architecture and town planning. She earned her Ph.D in Architecture (Theory and History of Architecture) from the University of Coimbra (2008-2009), with a dissertation entitled “On city and fortification in Portuguese texts (1540-1640)”. She is a Researcher at the Centre for Social Studies, University of Coimbra. She is also Senior technician at the Portuguese Institute for Housing and Urban Renewal (IHRU), where she has been a member of the SIPA (Architectural Heritage Information System) team since January 2010. Her research interests are: early modern fortified towns; treatises on architecture, town planning and related areas; cataloguing methods for the urban and architectural heritage.