Chapter 7

An Insight into Mediterranean Naval Architecture in the Sixteenth Century Through the Texts of Nicolò Sagri (1538–1571). A Comparative Perspective with Ibero-Atlantic Shipbuilding

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In 1997, the existence of a manuscript dealing with Mediterranean navigation and shipbuilding in the sixteenth century was revealed in the USA at an auction organised by Christie. Four years later, in 2001, the contents of this document entitled '*Il Carteggiatore*' (The Cartographer) by Nicolò Sagri (1538–1571) were made available to researchers after being donated to the James Ford Bell Library of the University of Minnesota (Dell'Osa 2010)[1]. Although lost for a long time, its existence was known due to its evocation by Bartolomeo Crescentio in *Della Nautica Mediterranea* (Crescentio 1602). Aware of the high interest of this manuscript, the French naval historiographer Auguste Jal had searched for it in Italy, in vain,

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[1] Sagri, Nicolò, 1571, 'Il Carteggiatore', University of Minnesota, TC Wilson Library manuscript n°31951SA0111372C. Online access: https://umedia.lib.umn.edu/item/p16022coll185:1222?q=sagri.

The present study is the result of collaboration between its three authors within the framework of the 'ModernShip Project'. This project has received funding from the European Union's Horizon 2020 research and innovation programme, Grant Agreement no 843337 (Marie Sklodowska Curie Actions). The translation of Sagri's manuscript on which this study relies was carried out by F. Ciacchella.

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A. Crespo Solana et al. (eds.), *Heritage and the Sea*,
https://doi.org/10.1007/978-3-030-86460-6_7

between 1834 and 1835 (Jal 1840, p. 25). Its recent reappearance is a boon for research into the maritime history and Mediterranean shipbuilding of the modern period.[2]

Dated 1570, the manuscript contains 107 folios written in Italian. Its author is Nikola Sagroević, a naval officer from Ragusa (today Dubrovnik) whose duty of the training of ship's officers has motivated the writing of this treatise. The text is rich and of great value for the knowledge of the Ragusan Navy of the time, of which it reveals many aspects: life on board, role of the captain and officers, financial aspects related to the remuneration of seamen and officers, etc. It also deals with cosmography and astronomy, maritime routes and cartography, bearing in mind that it was originally intended for the training of the *Carteggiatore*, the officer in charge of navigation and maps on board. These aspects of the manuscript gave rise to a study and transcription published by Dario Dell'Osa (2010). Then a second transcription and translation into Croatian has been published (Bondioli et al. 2020).

For researchers, *Il Carteggiatore* is an invaluable new document that offers a brief but accurate overview of Italian-influenced shipbuilding of the early modern period through the example of a typical merchant ship of that time, a *nave*, the method of calculating its tonnage, the making of sails and anchors. This information is of great importance taking in account that shipbuilding in the Mediterranean nautical space of that period is still largely unknown due to the paucity of archaeological and written documentation available: To date, the studies of Mediterranean naval architecture of the sixteenth century from archaeological sources come mainly from three shipwrecks located in France: the *Lomellina*, Villefranche-sur-mer (Guérout et al. 1989), the Calvi I wreck (Villié 1989, 1990, 1991), and the Mortella III wreck (Cazenave de la Roche 2020).

Concerning the texts from the Renaissance, they are mainly Venetian and mostly devoted to rowing ships. They are the first known writings to deal with shipbuilding and are surprisingly early. The first Venetian texts appeared at the end of the fourteenth century with the 'Libro de navegar' (Bondioli 2017), and in the fifteenth century with three major manuscripts: the 'Libro' by Michele da Rodi (Long and Mc Gee 2009), the 'Libro di apunti' c.1444, by Zorzi 'Trombetta' da Modon (Anderson 1925), the 'Ragioni Antique' (Chiggiato 1987).[3] If we except those that only focus on ships of galleys family, there are few writings dealing with *navi* in the sixteenth century: we should mention the '*Instructione sul modo di fabricare galere*'

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[2] The only known ragusan treatise on navigation and shipbuilding before Nicolò Sagri is that of Benedetto Cotrugli (Benedikt Kotruljević) dated to the middle of the fifteenth century (1464). Discovered in the 1990s, this text is kept in the Yale University Library. It was translated by D. Salopek in 2005, then studied and transcribed by P. Falchetta (Falchetta 2009, 2013).

[3] 'Libro de navegar', (Civic Library Angelo Mai MA334, Bergamo, Italy. Accession Number: ex Σ. VII. 29. Italy); manuscripts '*Libro*' by Michele da Rodi (private collection); the '*Libro di apunti*' c.1444, by Zorzi 'Trombetta' da Modon British Library (BL), Cotton ms. Titus A XXVI; the '*Ragioni Antique*', National Maritime Museum Library (NMML), Greenwich, ref. Cid. NVT.19.

by Theodoro de Nicolò, which contains 43 folios[4] and the '*Misure de navilii*' (1567) of about ten folios and recently published (Nicolardi 2014). We should also mention Genoese and Ragusan notarial contracts published, among others, by Gatti (1975, 1999) or Borghesi and Calegari (1970). To this narrow textual *corpus*, we should finally add the later work of the Roman Bartolomeo Crescentio, published at the beginning of the seventeenth century (Crescentio 1602), which evokes the work of Sagri, parts of which he resumed.

In this context of documentary poverty, and considering the key role played by Mediterranean technical culture in the European shipbuilding layout of the early modern period, Nicolò Sagri's treatise makes a very useful contribution to enriching our knowledge and meagre *corpus* of texts available for its study (Table 7.1). This is the reason for writing this chapter, which is divided into three parts: The first is a study of the architecture of a *nave* of *30 piè*[5] *de larghecza* that Sagri provides in Chap. 6 of his treatise. On the one hand, it aims to reconstruct her shapes and dimensions and, on the other hand, to place her typology in the context of Mediterranean shipbuilding of the time.[6] The second part aims to parallel the architectural profile of Sagri's *nave*, as shown in his Chap. 6, with the architecture of Iberian merchant ships of the same period revealed by Spanish and Portuguese authors and archaeology.[7] Finally, the last part is an analysis of Chap. 7 of the *Carteggiatore* devoted to the calculation of the tonnage of the *nave*. It aims to explain the method recommended by Sagri and to put it into perspective with the different calculation systems in use at that time, especially in the Iberian world.[8]

1 *Il Carteggiatore*'s Contribution to the Knowledge of Naval Architecture of Ragusan/Italian Influence. Study of the Dimensions, the Proportions, and Reconstruction of Sagri's *Nave*

Entitled '*Delle tre principalli missure della nave*' ('Of the three main measurements of the *nave*'), Chap. 6 of the *Carteggiatore* contains the essential information concerning the architecture of the *nave*. It is composed of only four folios written on both sides, from f°13R to f°16 V, a total of just over 1000 words. Despite its brevity,

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[4] 'Instructione sul modo di fabricare galere o Arte de far vasseli' by Theodoro de Nicolò, 1550. Biblioteca Nazionale Marciana di Venezia, manoscritti italiani, cl. IV cod. XXVI (5131). A copy of this manuscript in the Archivio di Stato di Venezia (ASV) under the title 'Arte de far vasselli', Archivio proprio Giacomo Contarini. sec. XVI, Miscellanea Codici 373. Manuscript Online: http://echo.mpiwg-berlin.mpg.de/MPIWG:7KTSNYA6.

[5] Units of measurements used in this text are explained in Table 7.1.

[6] This part is written by Arnaud Cazenave de la Roche.

[7] This part is written by Cayetano Hormaechea.

[8] This part is written by Fabrizio Ciacchella.

Table 7.1 Linear and volume measure units for ships mentioned in the article

Origin	Linear units		Volume units	
Venice	*piè (piede)* = 16 *dita veneziane*	0.3477 m	Venetian *botta/botte:* estimated capacity (Lane)	c. 0.600 m^3
	Passo geometrico = 5 *piè (piedi)*	1.7385 m	Estimated weight (Lane)	c. 640 kg
			space occupied in hold = 10 *staia*	0.833 m^3
			Venetian *staio/ster*	0.0833 m^3
Sicily			*Salma generale*	0.2655 m^3
Naples			*Carro* = 36 *tomoli*	1.9915 m^3
Genoa[a]	*Palmo di canna* = 12 *dita genovesi*	0.2478 m	*mina* = 4 Genoese *staja* (1310–1550)	0.1058 m^3
			(after 1550)	0.1121 m^3
	Gobito, chobitto, goa = 3 palmi di canna	0.7432 m	foreign *botte:* estimated capacity	c 0.445 m^3
			space occupied in hold = 2.5 *salme*	0.6638 m^3
			Corresp. Weight = 10 *cantari*	476.5 kg
Spain			*Pipa andaluza: capacity*	0.4437 m^3
			Space occupied in hold = 4 cubic *codos castellanos* or 4 cubic *codos de ribera* (according to different estimates)	0.691–0.761 m^3
	Codo castellano = 32 dedos	0.557 m	*Tonelada de carga / tonel castellano = space occupied by 2 pipas andaluzas = 8 cubic codos castellanos*	1.382 m^3
	Codo de ribera = 33 *dedos*	0.575 m	*Tonel macho* = space occupied by 2 *pipas andaluzas* = 8 cubic *codos de ribera*	1.521 m^3
	After 1590, all measures were in *Codos de ribera* and *toneles machos*			
Portugal	*Palmo de Goa = 14 dedos*	0.2566 m	*Tonelada* (Portuguese): space occupied in hold = 6 *salme*	1.593 m^3
	Goa, côvado real = 3 palmos	0.77 m		
	Rumo = 2 goas	1.54 m^3		

the part that Sagri dedicates to naval architecture is dense. As a result, it allows a fairly precise insight of the architecture of the forms of Ragusan shipbuilding, at least that of the *navi*, the merchant ships of the time. In this sense, Nicolò Sagri‘s text is in line with the Italian tradition, which is characterised by a network of measurements that allow the architectural profile of the *nave* to be set out, but which is, on the other hand, free of any information on the carpentry techniques employed. What is also innovative and original in Sagri's text, compared to those of the fifteenth century Venetian authors, is that the description of his 30-*piè nave* is based, to a large extent, on a set of rules of proportion that link the measurements together (see Table 7.3). Therefore, the application of these proportions to measurements other than those he gives for his example of 30 *piè de larghecza* would—a priori—make it possible to define the profile of any *nave* of other dimensions.

1.1 The Nave

A few words on this typology of ships are necessary before going into detail of the architectural description of Sagri's *nave*. Its origin is not clear, it is said to date back to very ancient times, to the end of classical antiquity, according to Furio Ciciliot (2005, p. 182, 185), but the first written attestations appear at the end of the twelfth century. For his part, Jacques Heers states that this type of ship was introduced in Genoa in the twelfth or thirteenth century by Basque sailors (Heers 1958, p. 109). It should be pointed out that the *navi* were private merchantmen. Although they were described by the fifteenth and sixteenth centuries shipwrights of the Venice Arsenal, they were built in private shipyards (Lane 1934, p. 46). As is the case with most types of ships, their physiognomy has changed significantly over time. In the thirteenth century, the *nave* was equipped with two lateral rudders and carried two masts rigged with Latin sails (Ciciliot 2005, p. 184). From the fifteenth and sixteenth century, its characteristics can be summarised as follows:

- Nautical spaces: Typical Mediterranean merchant ship, it was in use in the trade of all the Italian cities and in Ragusa, but it was particularly used by Genoa, while Venice, for example, turned quite early to the development of merchant galleys, the '*galee grosse da merchato*'.
- Tonnage: The *nave* was a large-capacity vessel, the largest Mediterranean merchant ship (Gatti 1999, p. 145). Her tonnage has evolved over time. It was in the fifteenth century that the largest units specialised in the transport of alum were operating in Genoa. Manlio Calegari points out that in 1509 the average tonnage of *navi* in Genoa was 14.000 *cantari*, i.e. a little less than 670 metric tons of net deadweight and 930 m^3 of net tonnage; and that the smallest units had a tonnage of more than 8.000 cantari, i.e. 380 metric tons of net deadweight and 530 m^3 of net tonnage (Borghesi and Calegari 1970, p. 15–16).
- General characteristics: in the sixteenth century, the *nave* was rigged with three masts with square sails on the foremast and mainmast and a Latin sail on the mizzen mast. It was generally provided with three decks, two *cubiertas* and a *tolda*.[9] Finally, although the *navi* were commercial ships - they were usually armed with several pieces of artillery to enable them to defend themselves against the pirates that proliferated in the Mediterranean.

The model of ship described by Sagri is a *nave* 90 *piè* (90 Venetian feet, i.e.32 m) of length, 30 *piè* (about 10.50 metres) of maximum breadth. With a tonnage of between 2500 and 2600 *salme*, or about 10,000 to 10,400 *cantari*, Sagri's *nave* is therefore situated in the lower part of the average capacity of this typology of merchant ships of the time.

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[9] The question of the number of decks has given rise to much confusion. We attempt to clarify it in the part that deals with the horizontal structures of the nave.

1.2 The Relationship Between the Three Main Dimensions of the Ship

The definition of the relationship between the large dimensions of the ship are at the basis of any architectural project and, at the beginning of the modern era, there was a rule of proportion that was widely spread and in use in both Atlantic and Mediterranean nautical spaces, stated under the name of '*As-Dos-Tres'* by Spanish authors. In its first meaning, the maximum breadth is set as a referent (*As*) which multiplied by two gives the keel length (*Dos*) and by three gives the total length (*Tres*) of the ship:

$$\mathrm{B}(As);\mathrm{K}(Dos) = As \,\mathrm{x}\, 2; \mathrm{L}(\mathrm{Tres}) = As \,\mathrm{x}\, 3. \qquad \mathrm{B} = \mathrm{Breadth}; \mathrm{K} = \mathrm{Keel}; \mathrm{L} = \mathrm{Length}.$$

Thomé Cano expressed this rule most clearly: '…all the Spanish, Italian and other masters of shipbuilding have the practice of giving to one codo at the breadth, two to the keel length; and to another codo at the breadth, three to the overall length, and to three co-dos at the breadth, one to the flat width; and for the depth, three quarters of the breadth' (Cano 1611, p. 15).

We do not know the origins of the *'As-Dos-Tres*'rule, we only know that it is inherited from a long tradition that takes its roots in the early modern era and, in the symbolism of the Renaissance, that is perhaps a religious allegory of the Holy Trinity and/or of the 'Divine Proportion'enunciated in the thirteenth century by the Italian mathematician Leonardo Fibonacci, whose numbers in his famous series begin with 1, 2, and 3.[10]

Some builders of the time stated the rule with a variant which does not retain the dimension of the keel in this triple relation of proportions, but that of the depth of hold. Some authors express the 'As-Dos-Tres'rule, some with reference to the keel, others to the depth of hold, some both, some neither. The only ratio systematically mentioned being that of length/breadth (Cazenave de la Roche 2020, p. 10). For this part, Sagri uses the rule with reference to the depth of hold: 'It is well known that each body [of a ship] has three main measurements, which are length, width and height or depth, without which it would not form a body' (f°13R).

Already in the second folio of his chapter, he advocates a relation of proportion between these three main measures as follows: '...I shall say only [to illustrate] the three principal measurements of this *nave* that you should know that it should be three times as long between the bow and the stern at the level of the second deck as her greatest width at the level of the second deck, and her height or depth which we

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[10] Leonardo Fibonacci (1175-c. 1250), a native of Pisa, was the author of the algebraic sequence called 'Divine Proportion'. It is designed as a series of numbers, each of which is the sum of the two preceding ones (1, 1, 2, 3, 5, 8, etc.).

call *pontalle* should be at the level of this second deck half that width, and this is the fairest and best proportion that one can imagine...’(f°13v, L.5 to 15).

This sentence, which we have considered useful to reproduce here, is of a great importance as it defines the basis of the rule of proportion which will govern the main nautical characteristics of the *nav*e. In short, it states that:

$$\mathrm{B}(As);\mathrm{L}(\mathrm{Tres}) = 3 \times As; \mathrm{D}(\mathrm{Depth\ of\ Hold}) = \frac{1}{2} \times As.$$

To our knowledge, Sagri is the first Mediterranean author to state the *‘As-Dos-Tres*‘rule and, as we have seen, he does so by taking the variant that establishes the depth of hold as one of the three great measures rather than the keel. After him, but without explicitly mentioning it, Bartolomeo Crescentio expressed the rule in an identical way through the example of a ship whose dimensions he laid out (Crescentio 1602, p. 68). It would be interesting in the future to check whether this formulation breadth/length/depth of hold could be of Mediterranean origin, bearing in mind that, as Cayetano Hormaechea points out, Iberian authors tend to express it with reference to the length of the keel rather than the depth of hold. Notwithstanding this, the issue raised by the evaluation of the proportions stated by the builders who refer to the depth of hold is the vagueness that exists in the definition of this architectural notion because some builders measure it up to the first deck, others to the second or to the maximum breadth, or still others do not specify it. However, Sagri specifies that the depth of hold of his *nave* is measured up to the second deck and that her height is ½ times her maximum breadth. We will come back to this point. The *‘As-Dos-Tres*‘rule raises several questions:

- One of them concerns the nautical characteristics of ships built with these proportions: In order to determine accurately and completely these characteristics, a study through hydrodynamic calculations would probably be necessary. In the frame of this study we will settle for stating the nautical qualities mentioned by Sagri: according to him, ships of *‘As-Dos-Tres*‘proportions are ‘better than others under sail, they have in particular a good ability to sail upwind’ (f°13 V-L.3). Their second quality is that they are manoeuvrable in the sense that ‘they respond better to the rudder than others’ (f°13 V-L.4). It should be added that a ship whose length is only three times the size of her maximum breadth offers good load capacity and stability to the detriment of its speed. And actually, it is essentially for these reasons that the *‘As-Dos-Tres*‘rule was favoured for merchant ships.

Several texts bring evidence of the use of the rule in the second half of the sixteenth century in the Mediterranean for merchant ships. For Venice, the merchant *nave* of *piè 20 en bocha* by Theodoro de Nicolò illustrates it with a ratio of 1: 2.17: 3.11, thus very close to the *‘As-Dos-Tres*‘rule, or the *nave* of *nave de 14 passa en cholonba* by ‘Misure di Navilii’ which also fits precisely to it. In Genoa, notarial contracts specifying the technical characteristics of the *navi* to be built or sold attest to this (Gatti 1975).

For warships, the situation was often different. In the sixteenth century, with the development of the architectural concept of the battery, ships specialised in a warlike function appeared. Their breadth/length ratio reached 1–4, which reflects a prioritisation of speed over cargo capacity.[11] In the Mediterranean this fact is evidenced in the texts by Theodoro de Nicolò who describes a warship, the '*galeon grande*' of 37 ½ piè of maximum breadth and 20 *passi* (100 *piè*) of keel lengths with a more stretched shape with a ratio of 1: 2.67: 3.6.1[12] Nevertheless, in the last third of the sixteenth century we still see in the Mediterranean war galleons built on the model of the *'As-Dos-Tres'*rule. This fact is documented by an *asiento* between Philip II and the Ragusan Pedro de Ivella dated 1590 for the construction of 12 war galleons made in various Italian and Ragusan shipyards that adopted these proportions (Hormaechea et al. 2012; Casabán 2017).[13] Although forming a war squadron called '*escuadra Ylírica*', when these galleons were not on a war expedition, Pedro Ivella used them for commercial transport tasks. This raises the question whether their still multiple function could have favoured the *'As-Dos-Tres'*rule for their construction. Several texts also evidence the habit of giving a more elongated longitudinal shape to warships, not only in the Mediterranean, but also in the Atlantic area.

Another question also arises regarding the geographical and chronological boundaries that frame the use of the *'As-Dos-Tres'*rule: after stating that these proportions are the 'fairest and best that can be imagined', Sagri specifies '...although few ships today in our country are built in this way, whereas the old ones were built in this way' (f°13v, L.16 and 17). He adds that 'today the Genoese still build them in this way, as do the Biscayans and the Portuguese...' (f°14R, L.1-2). This sentence is important because it confirms that at the time he wrote his work, in 1570–1571, the rule in question was in use in both the Mediterranean and Atlantic areas. In Ragusa, however, it seems to indicate that it was no longer observed as it was before. However, according to the technical characteristics of the ships of Pedro Ivella's fleet of 1590, both those built in Naples and Ragusa had proportions in accordance with the *'As-Dos-Tres'*rule. It can therefore be deduced that 20 years after Sagri's death, it was still in use in Ragusa's shipbuilding. In the continuity of Sagri, at the beginning of the seventeenth century, the Spanish builder Thomé Cano also gave a universal character to the rule in 1611 by stating that it was used by 'all the masters of Spain, Italy and other nations'(Cano 1611, p. 15). In the sixteenth and early seventeenth centuries, both the authors of shipbuilding treatises and archaeology confirm its use in Ibero-Atlantic construction, as we will see in the second part of this chapter.

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[11] The laws of hydrodynamics which associate an increase in the speed of movement of the hull with an increase in its waterline length are empirically known in the sixteenth century. They were first theorised mathematically by the British William Froude in the nineteenth century.

[12] 'Instructione sul modo...', *op. cit*., f°26 and 27.

[13] 'Relación de la fábrica de doce galeones de guerra de la Escuadra Yllirica de Pedro de Ivella y Estéfano Dolisti. Carta de Pedro de Ivella al rey, de 17 diciembre 1593'. AGS, Guerra Antigua, Leg. 380–105. Reproduction in MNM. *Colección Navarrete*, Tomo IX, doc. 27, MNM.

In the Mediterranean, the shipwrecks documented to date are of older chronology, located in the first third of the sixteenth century. These are the Lomellina (1516) and the wreck of the Mortella III (1527), both of presumably Genoese construction, and whose longitudinal profiles are more stretched than those recommended by the '*As-Dos-Tres*' rule, with ratios of 1: 2.56: 3.52 and 1: 2.48: 3.50 respectively. These ratios can be compared to those that seem to be in use in Venetian construction in the fifteenth century. In fact, Venetian authors of the period such as Michele da Rodi or Zorzi Trombetta da Modon gave their *navi* similar ratios. These observations must be interpreted with caution, since the paucity of archaeological and textual documentation in the Mediterranean—which is moreover limited to Italian shipbuilding—restricts our field of vision. As a hypothesis, it can be sum up that (see Table 7.2): Between the fifteenth century and the first third of the sixteenth century (Period 1), Mediterranean shipbuilding in its Italian representation -in this case Venetian and Genoese – seems to have given to merchant ships, the *navi*, a stretched longitudinal profile with ratios of around 1: 2.50–2.80: 3.50–3.80.[14]

In the sixteenth century, and in any case after the first third of the century (Period 2), the '*As-Dos-Tres*' rule -expressed in two variants, but whose constant is to link length to width by a ratio of 1 to 3- was in use throughout European shipbuilding, both Mediterranean and Atlantic. However, it applied mainly to merchant ships, while generally more stretched proportions were in use for warships. If Theodoro de Nicolò and Crescentio evidenced it for the Mediterranean, this practice was institutionalised in the Ibero-Atlantic space by Spanish ordinances at the beginning of the seventeenth century. From the last third of the sixteenth century, the period in which Sagri writes, the rule was still widely used, but some nations, such as Ragusa, no longer observed it as strictly as before. In the Ibero-Atlantic area an evolution of proportions also appeared in the same period with the emergence of a movement called the '*Nueva fabrica*'.[15]

1.3 Reconstruction of Shapes Relying on a Network of Secondary Proportions

1.3.1 The Transverse Shape: Depth, Width of Decks, Maximum Breadth and Waterline

From the second folio of his Chap. 6 (f°14 V), Nicolò Sagri addresses the question of the horizontal layout of the hull structures which will allow us to sketch the transverse shape of the *nave* which depends essentially on the depth of hold and width of

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[14] It must be outlined that the smaller is the tonnage of a ship, the more her shapes will be stretched. In fact, the '*As-Dos-Tres*' rule is only applicable to medium or large tonnage units.

[15] The '*Nueva fabrica*' is a movement that emerged in Spain in the last third of the sixteenth century under the impetus of builders such as Juan de Veas. It advocated stretched shapes to merchant ships that departed from the '*As-Dos-Tres*' rule. We will return to it in the next part of this chapter.

Table 7.2 Evolution of the ratios in the Mediterranean (15th-16th c)[a]

Period 1: fifteenth to mid sixteenth centuries												
	Michele da Rodi, *'Nave quadra'* c. 1434 (Venice)				Zorzi Trombetta da Modon, c. 1444, (Venice)							
Main measures	Ratios	*Paso*	*Pie*	Meters	Ratios	*Paso*	*Pie*	Metres				
Max. Breadth	1		26 1/2	9.22	1		28	9.74				
Keel length	2.45	13	65	22.62	2.59		72 1/2	25.23				
Length	3.58		95	33.06	3.80		106 1/2	37.06				
Depth of hold	1/2		13	4.52	2/5		11	3.83				
Flat	4/5		9 3/4	7.25	1/3		9	3.13				
Ton.					700 bote							
Source	(Michele da Rodi, 1434)				(Zorzi Da Modon, 1444)							
	'Lomellina' wreck 1516 (Genoa)				Mortella III wreck 1527 (Genoa)				*Nave Santa Trinita* 1548 (Ragusa)			
Main measures	Ratios	*Goa*	Palmi	Metres	Ratios	*Goa*	Palmi	Metres	Ratios	*Paso*	*Pie*	Metres
Max. Breadth	1			12.50	1		42 1/3	10.50	1		27 1/2	9.57
Keel length	2.56			32.00	2.48	19 1/3		26.00	2.36	13	65	22.62
Length	3.52	59		44.00	3.50	49 1/2		36.80	3.42		94	32.71
Depth of hold	1/2			6.70	1/2			5.26	1/2		15	5.22
Flat					1/3			3.45				
Stem overhang	4/5			10.00					2/3		19	6.61
Stern overhang	1/6			2.00	1/6			1.65	1/3		10	3.48
Ton.					12000/13000 cantari							
Source	(Guérout et al., 1989)				(Cazenave, 2020)				(Gatti, 1975, p.93)			

Period 2: Mid-sixteenth to seventeenth century												
	Nave 20 pie Theodoro de Nicolò 1550 (Venice)				*Nave* 14 passo in cholonba' Misure di Navilii 1567 (Venice)				Sagri's *Nave* 1571 (Ragusa)			
Main measures	Ratios	*Paso*	*Pie*	Metres	Ratios	*Paso*	*Pie*	Metres	Ratios	*Paso*	*Pie*	Metres
Max. Breadth	1		23	8.00	1		34 1/2	12.01	1		30	10.44
Keel length	2.17	10		17.40	2.03	14		24.36	1.94		58 1/8	20.23
Length	3.11		71 1/2	24.88					3		90	31.32
Depth of hold	1/2		11 1/2	4.00	2/5		14	4.87	1/2		15	5.22
Flat	1/3		7	2.44					1/3		10	3.48
Stem overhang	2/3		15	5.22					4/5		24 3/8	8.48
Stern overhang	2/7		6 1/2	2.26					1/4		7 1/2	2.61
Ton.									2500/2600 *salme*			
Source	(Theodoro de Nicolò 1550)				(Nicolardi 2014)				(Sagri 1571)			
	Calvi I wreck 1580/1600 (Genoa?)				*Nave* by Andrea Fava 1599 (*Santa Maria in Betelen*, Genoa)				*Nave of* pie 30 Crescentio 1602			
Main measures	Ratios	*Goa*	Palmi	Metres	Ratios	*Goa*	Palmi	Meters	Ratios	*Paso*	*Pie*	Metres
Max. Breadth	1	10 1/2		7.80	1		39	9.67	1		30	10.44
Keel length	2.18	23		17.00	2.31			22.33	2		60	20.88
Length	3.19	32 1/4		24.90	3.23	42		31.25	3	18	90	31.32
Depth of hold					4/7			5.45	1/2		15	5.22
Flat									2/7		9	3.13
Stem overhang	2/3			5.10	3/5			5.70				
Stern overhang	1/3			2.80	1/3			3.22				
Ton.					3000 salme				2565 salme			
Source	(Villié, 1989–1991)				(Gatti, 1975, p.72; 1999, p. 287-9)				(Crescentio, 1602, p. 70, 75)			

[a] Ratios are referred to the beam. Lengths and depth of hold are measured to the second deck

the decks. In the Italian shipbuilding tradition, the transverse shape of the ship was obtained by a scale of values, or offset, defined by the relationship between heights taken on several lines running above the keel (ordinate) and the breadth between the frames at these levels (abscissa). The first two heights, called '*trepiè*' and '*seipiè*', located, respectively, three and six *piè* from the '*tavola*', correspond to hull breadth values. Then comes the breadth at the level of the '*bocha*', which under the pens of the fifteenth century authors such as Michele da Rodi or Zorzi 'Trombetta' da Modon, corresponds to the line of the maximum breadth. But in the sixteenth century, under the pen of Theodoro de Nicolò, the *bocha* corresponds to a depth of 9 *piè* and the line of the maximum breadth takes the name of '*Regia*'. Finally, the scale of values is completed by the relationship between the heights and breadth of the decks. In the system proposed by Sagri, only the latter relationship is given, the concepts of *trepiè*, *seipiè,* and *bocha* are not mentioned.

The Number of Decks Before addressing the question of the relationship between the height/width of the decks, it is useful to point out that their number often gives rise to confusion due to the different ways in which the first transverse reinforcement structure of the hull can be considered. Indeed, depending on the constructive tradition, this may consist of a series of beams that structurally connect the two sides of the hull without necessarily being decked (or sometimes provided with a removable floor). In English the latter takes the name of orlop. In Spain, the authors speak of '*baos vacíos',*[16] the French authors of '*faux pont*' and, in this case, it is only the second transverse structure, the one with a fixed floor, which is called the 'first deck'. This semantic aspect can lead to confusion, and Italian shipbuilding, whose horizontal internal structures of the hull are called '*choverta*', '*coverta*', or '*coperta*', is no exception. The last and highest is called '*tolda*' (upper deck, '*puente*', in Spanish; formerly '*tillac*', in French). The numbering of the decks may therefore vary depending on the way the authors express themselves. For example, Luciana Gatti characterises the *navi* as a typology of ships usually with two decks (Gatti 1999, p. 146). But by two decks, it is necessary to understand here either two '*choverta*', without taking into account the 't*olda*', or two decks, independently of the orlop we have mentioned, which is sometimes overlooked in the description of the *navi*. For example, Gatti (1999, pp. 288–289) reproduces a construction contract dated 1599 for a *nave* with dimensions close to those of Sagri. The notary mentions the height of the first deck: '*Altezza prima coperta'* = 5.45 m. The structural need for an orlop between this deck and the ceiling is obvious, but it is not mentioned.[17] In general, we are dealing with a typology of ship with three transversal structures and, which is the case of the Sagri's *nave*: In his text, he mentions a '*prima cho-*

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[16] This Spanish terminology expresses the absence of a deck. In the remainder of this article, it will be referred to as 'naked' beams.

[17] Archivio di Stato di Genova (ASG), Notai antichi, Rivanegra Abramo filza 26, Genova, 8 Aprile 1599: Contract dated 1599 for a *nave* with dimensions close to those of Sagri.

vertta', a '*sechonda chovertta',* and a '*tolda*'. From a certain tonnage, in addition to these three decks, there was in addition a *'ponte di corridoio*' or orlop.[18]

As we shall see, in the example given by Sagri, the main reference used to determine the depth of hold and the maximum breadth is the '*sechonda coperta*' under which he specifies that the cargo is located when it consists of grain: 'The so-called second deck must be the one under which the entire cargo of this *nave* can be stored when it is composed only of grain'.

Height of the Decks Sagri explains a rule of proportion that allows to locate the height of the three decks of his *nave*: 'This depth, …we call *pontalle*, must be divided into five parts, three fifths of which will go from the bottom to the first deck, and the remaining two will be between these two decks [first and second deck]' (f°14 V, L9 to 13). '... we will have 27 ½ piè from the bottom of the *nave* to the upper part of the bulwark in the middle of the upper deck of this nave' (f°15 V, L3). This distribution makes it possible to locate the first deck at a height of 9 *piè* (3.13 m), the second at 15 *piè* (5.22 m), the third deck (*tolda*) at 22 ½ *piè* (7.83 m) and finally the total height at the bulwark of 27 ½ *piè* (9.57 m).

Breadth of the Decks and the Flat (at Mid-Ship) The first deck: At f°14 V, Sagri gives the proportion to set the width of the first deck: 'The width of the first deck will be three times its depth of hold' (14 V, L16 and 17). He returns to this measure in f°16R where he states: 'its width at the first deck will be 27 *piè*'.

The second deck: its width is part of the '*principali mesure*' stated above; it is equal to 30 *piè* (10.44 m) and also represents the line of the maximum breadth.

The third deck (*tolda*): its width is not mentioned, but in the logic of the transverse shape mentioned by Sagri, it must be a little bit less than the first deck.

The flat: the width of the flat, '*piano*' or '*fondi*', is set by the following ratio of proportions: 'the flat is 1/3 of its width [of the deck], or 3/5 of the depth of hold and as much the runs' (f°14 V, L13). Note that the first proportion corresponds to a value of 9 *piè* (3.13 m) and the second 10 *piè* (3.48 m). Nevertheless, a little further on in the text (f°16R, L1), Sagri specifies that the flat of his *nave* is 9 *piè*. As we saw, he states that at the stern, the height of the run is also 9 *piè* (f°16R, L5). On the other hand, he does not specify anything about the transverse shape of the master-floor. We do not know whether it has a strong rising as archaeology has revealed in the Genoese shipbuilding (Cazenave de la Roche 2020, pp. 118–122) or whether it is flat, as in the Iberian shipbuilding tradition. In our reconstruction of Sagri's master-frame, we have opted for a hypothetical intermediate shape (Fig.7.1a).

Finally, he provides information that determine the width of the transom and place the waterline at the height of the second deck once the *nave* is loaded: 'the [distance between the] fashion timber at the level of the heads of the first wale of the

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[18] For example, in the Ragusan construction, we can cite Pedro de Yvella's '*assiento*', mentioned above. Indeed, the characteristics of the galleons explicitly mention the presence of '*baos vacios'* under three decks: the two '*cubiertas'* and the '*puente*'.

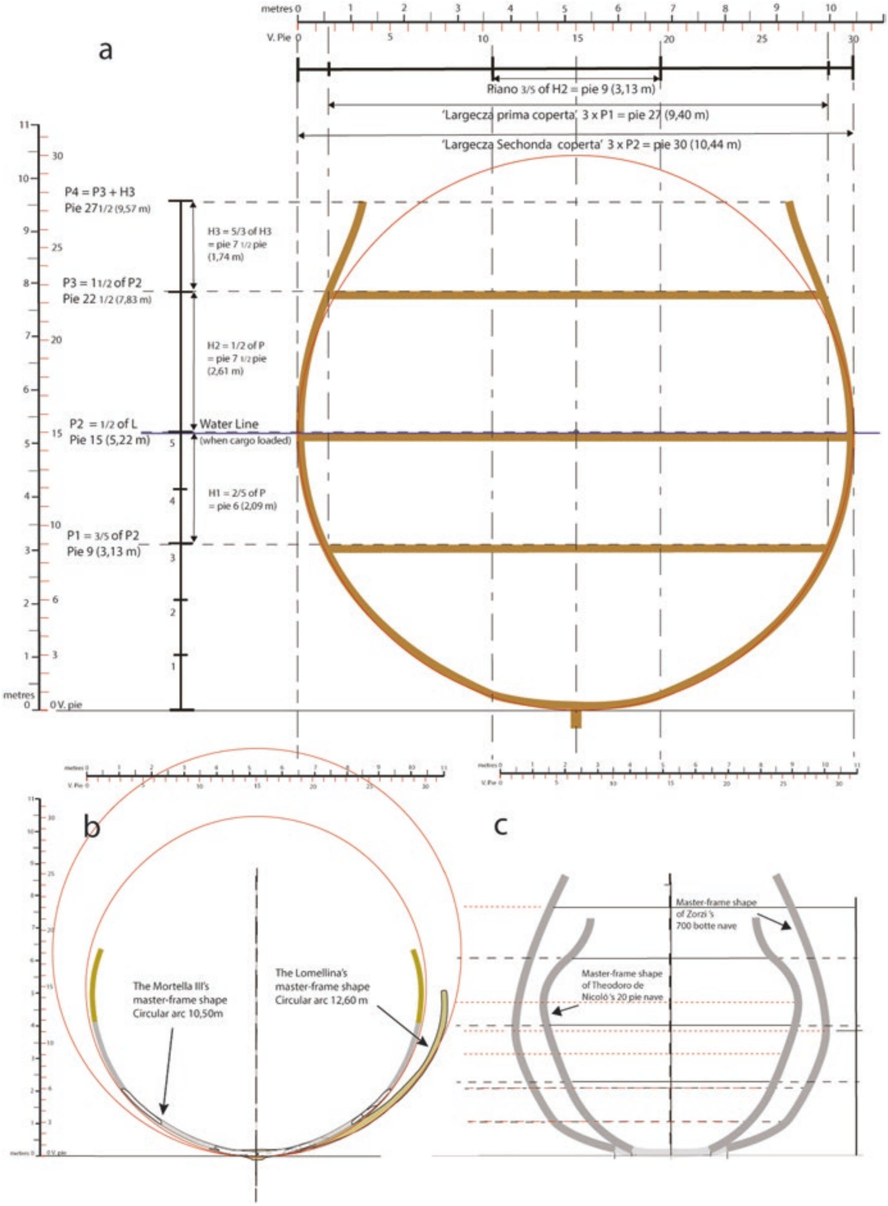

Fig. 7.1 (**a**) Reconstruction of the transverse shape of Sagri's nave; (**b**) Circular transverse shape of the Genoese navi of Mortella III and Lomellina (radii); (**c**) Oblong shapes of the profiles of the Venetian navi of Michele da Rodi and Theodoro de Nicolò. Illustration A. Cazenave

first deck [,] that is to say, where (14 V, L17–19) the waterline will be when the *nave* is loaded, must be half this width [of the first deck]' (15R, L1–2). As a result, the transversal shape of Sagri's *nave* can be reconstructed as follows:

The transverse shape of Sagri's *nave* highlighted by the proportions set out in his Chap. 6 reveals a circular profile following a radius of 5.22 m. It can be compared to the shapes observed on the Genoese wrecks of Mortella III, Lomellina and also Calvi I, whose origin is, however, less formally established. In this sense, the transverse design of Sagri's *nave* appears closer to the typology of form highlighted by archaeology in the Genoese shipbuilding than the shapes disclosed by the Venetian texts of Michele da Rodi or Zorzi da Modon, for the fifteenth century, and Theodoro de Nicolò, for the sixteenth century, whose profiles are more oblong with a tendency towards ellipsoidal shape (Fig. 7.1b, c).

In fact, Venetian shipbuilding is characterised by transverse profiles that make several arcs of tangent circles coexist. However, in the fifteenth century these shapes were not obtained by the projection of circular arcs, but by an arithmetic construction with a scale of values that we mentioned earlier. The geometrical construction of the transverse form using tangent arcs of circles appeared -to our knowledge- in the middle of the sixteenth century with Theodoro de Nicolò. Without abandoning the scale of the '*trepiè*', the 's*eipiè',* and the '*bocha*', he, however, used for the first time an '*ano de valangin dal magier de bocha fin a la tolda*' ('circle arc from the beam of bocha to the *tolda*') and another '*ano de valangin dal fondi a la bocha*' ('circle arc from the floor to the *bocha*'). This design the master-frame shape with tangent arcs of a circle of Venetian origin influenced English shipbuilding, which took up and developed it in the last third of the sixteenth century (Cazenave de la Roche 2020, pp. 13–22). It is described by Mathew Baker in his 'Fragments of Ancient English Shipwrightry'.[19]

Thus, although located in the Venetian zone of influence, the transversal architecture of the Ragusan *nave* highlighted by Sagri seems to be different from that advocated by the Venetian texts we know. On the other hand, it is similar to what archaeology has taught us about Genoese architecture, but also to that of the Iberian world, where the single arc of a circle was widely used to give shape to the master-frame. Iberian authors widely advocate the use of a single arc of a circle for the design of the transverse shape of merchant ships (Hormaechea et al. 2012, p. 186; Cazenave de la Roche 2020, pp. 13–15).

Rake of the Stern It is given by a simple proportion: 'for every *piè* of vertical height, half a *piè* of overhang will be given' (F°15R, L2–4). This ratio, illustrated in the manuscript by a small sketch in the margin (F°15R), results in a rake for about 65° to the horizontal (exactly 63.43°, calculated by trigonometry).

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[19] Mathew Baker, *c.*1580, 'Fragments of Ancient English Shipwrightry.' Cambridge, Magdalene College, Pepysian Library, Ms. 2820.

1.3.2 The Longitudinal Shape

Shape and Overhang of the Stem Sagri set out a system of his design to define the shape and overhang of the stem: 'I advise that we follow a new way that I have found, which consists in taking the height of the *nave* from the ceiling to the last wale [,] that means, to the path of the gangway at mid- upper deck and we draw in a line as long as the said height will be [...], ... then at one end of this line a compass point will be placed and the other point at the other end of this line, and with this opening, a circle will be drawn inside which the fourth part will be taken, which will constitute the bow' (f°15R, L4–17). In short, Sagri is using a circular arc whose centre is located at the intersection of the horizontal line of the upper deck (*tolda*) with the vertical line passing through the fore end of the keel (Figs. 7.2 and 7.3).

Regardless of the 'new method' that he exposes, Sagri specifies that 'in the past', the builders gave the bow two *piè* of overhang to each *piè* of depth and that 'today' they give an overhang of only one *piè* and 2/3 at each *piè* of depth (F°15R, L4–5). In fact, the Sagri system produces a result very close to that in use at the time when he was writing.

The Curvature of the Wales The wales (*centa* or *zenta*) are external longitudinal reinforcements essential to the structure of the hull. In the last part of his chapter Sagri describes in detail their positioning and their curvature (*archamentto* and *cerviecza*) which helps to understand its shape: At mid-ship, the two first wales are

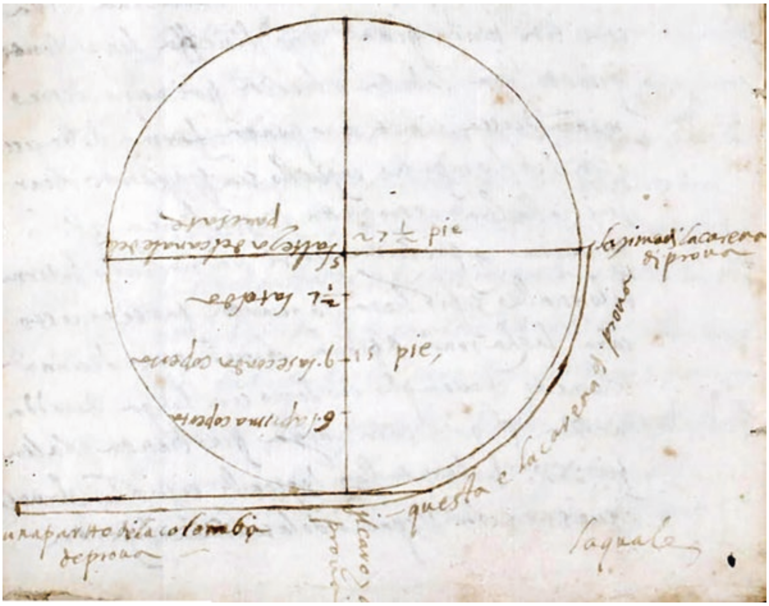

Fig. 7.2 System set out by Sagri to design the stem-post (F°15 V)

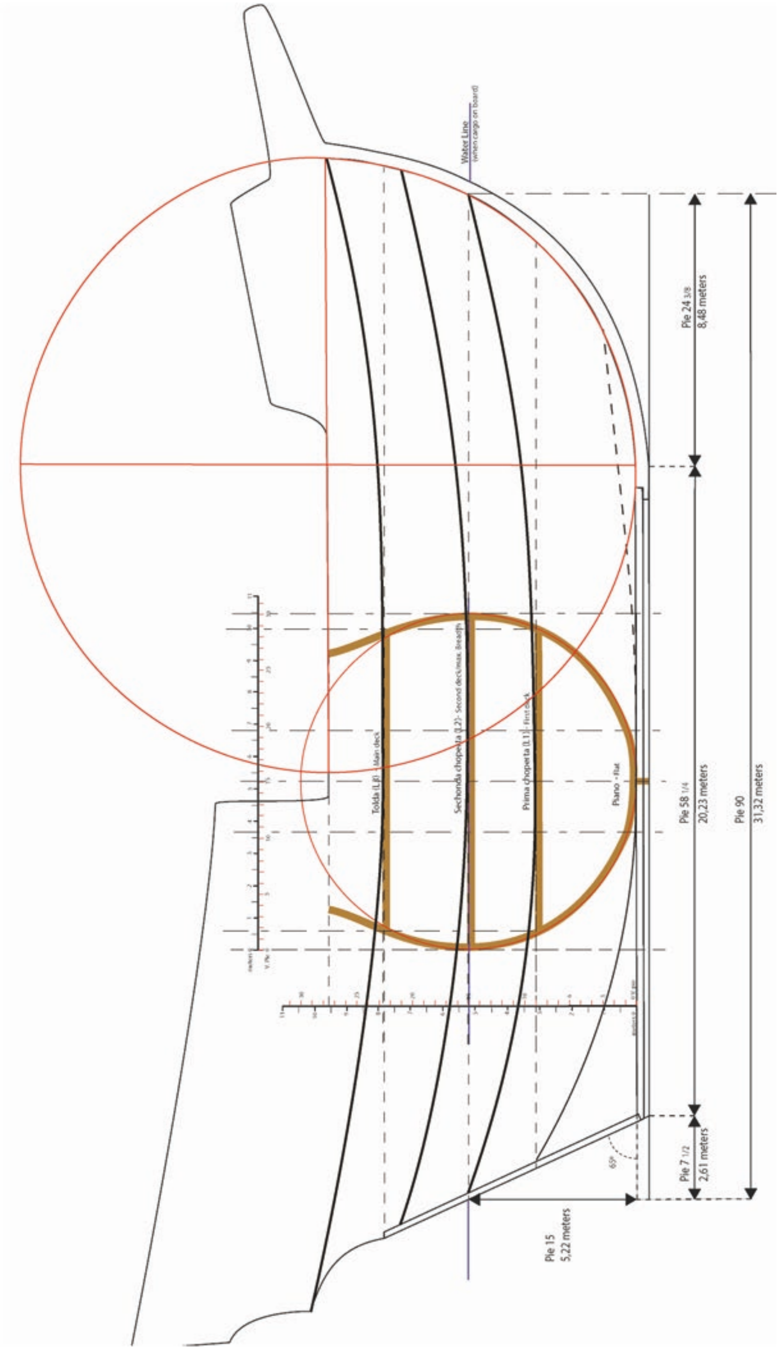

Fig. 7.3 Reconstruction of Sagri's nave longitudinal shape and dimensions. Illustration A. Cazenave de la Roche

located, respectively, at the level of the first and the second deck. The space between them is therefore 6 *piè* (f°16R, L14–16, f°16 V, L1). They continue their course towards the bow and the stern as follows: the heads of the first wale reach the level of the second deck. As for those of the second wale, they are located at a distance of 6 *piè*, but this time not measured vertically, but according to a sloped trajectory. At the stern, it follows the line of the fashion timber and at the bow, the line of stern, so that the two wales come closer at the end of their course (f°16 V, L10–14).

In the end, the longitudinal shape of the ship reconstructed following Sagri's indications can be represented as in Fig. 7.3. Measures and ratios are given in Table 7.3.

Table 7.3 Proportions of Sagri's *nave*

	Ratio to depth	Ratio to breadth	Piè	Metres
HEIGHTS				
Bulwark to top of the keel	1 5/6 D2	11/12 B	27 1/2	9.57
Bulwark to third deck (*Tolda*)	2/3 D3		5	1.74
3rd deck to keel	1 1/2 D2	3/4 B	22 1/2	7.83
3rd deck to second deck	1/2 D2		7 1/2	2.61
2nd deck to keel	D2		15	5.22
2nd deck to first deck	2/5 D2		6	2.09
1st deck to keel	3/5 D2		9	3.13
Run	3/5 D2		9	3.13
BREADTHS				
2nd deck	2 D2	1 B	30	10.44
1st deck	3 D1		27	9.40
Flat	3/5 (or 2/3) D2	3/10 (or 1/3) B	9	3.13
Between fashion pieces (at level of the heads of first wale of first deck)		1/2 B	15	5.22
LENGTHS				
2nd deck (water line)	6 D2	3 B	90	31.32
Keel	3 7/8 D2	1 15/16 B	58 1/8	20.23
Overhang stern at bulwark	1/2 D4		13 4/5	4.80
Overhang stern at second deck	1/2 D2	1/4 B	7 1/2	2.61
Overhang stem at bulwark	1 D4		27 1/2	9.57
Overhang stem at second deck	1 5/8 D2	13/16 B	24 3/8	8.48

D1 = Depth at first deck, D2 = Depth at 2sd deck (*pontalle*), D3 = Depth at third deck (*tolda*), D4 = Depth at the top of the bulwark. B = Breadth. Piè = 0,348 cm

2 Mediterranean and Ibero-Atlantic Naval Architecture: A Comparative Study of Two Ways of Building Ships in the Sixteenth Century in the Light of Texts by Nicolò Sagri and Iberian Authors

2.1 Preliminary Considerations

In his Chap. 6 of *Il Carteggiatore,* Nicolò Sagri warns us that, at the time he was writing, the main proportions he proposed for the construction of a merchant ship had already fallen into disuse in his city of Ragusa, but that they were still used by the Genoese, Basques, and Portuguese. This is why we try to contrast the ship he describes with the constructive uses on the Atlantic coasts of the Iberian Peninsula and, in particular, those of Portugal and the Eastern Cantabrian.

As we already saw, the proportions of Sagri's *nave* taken at the level of the second deck meet the '*As-Dos-Tres'* rule, with the depth used as one of the units of reference. However, for purposes of comparison with other Iberian ships, we have taken the length measurement on the upper deck (*tolda*). This means that in the comparison Table (Table 7.4), the Sagri's ratio length / breadth is slightly higher. Something similar happens with the depth. We have decided to maintain Sagri's criteria and we adapted the measurements to reflect the height taken from the flat and not from the ceiling. Finally, Sagri's *nave* is a merchant which presents differences with the Spanish warships. For this reason, we will only compare her with merchant ships.

2.1.1 Criteria for Depth Measurement

There may be significant differences in the criteria used by different authors to establish the dimensions of the hull. It is therefore necessary to make the appropriate corrections to make them comparable. Especially when taking the measurement of the depth of hold which may cause interpretation problems, so we will spend a few lines to clarify that.

Sagri's drawing confirms that the measurement of the depth of hold is taken from the upper face of the keel up to the second deck (f°14 V, Fig. 7.2). However, for comparison purposes, it should be noted that, in the sixteenth century in Spain, two ways of measuring the origin or lower end of the depth of hold were used. Here are some documentary references that perfectly illustrate the above in all their variants: Height from the flat up to the first fixed deck (Escalante de Mendoza 1575, pp. 22–23) and height from the flat up to upper deck: (Oliveira 1580, p. 124; García

Table 7.4 Comparison of the dimensions of the five ships studied

Ships	Sagri–1570 merchant ship		Oliveira 1580 18 *rumos* keel		Luis César 1589 16 *rumos* keel		San Juan 1565 whaling ship		García Palacio 1587 400-*ton*. Ship	
Units	*Pie Venice*	Metres 0.348	*Palmos de Goa*	Metres 0.257	*Palmos de Goa*	Metres 0.257	*Codos de ribera*	Metres 0.575	*Codos de vara*	Metres 0.557
Overall length	96 1/4	33.50	152 2/5	39.17	136	34.95	38 1/5	21.97	51	29.33
Maximum breadth	30	10.44	51	13.11	43	11.05	13 1/7	7.56	16	9.20
Stem overhang	26 3/4	9.31	36	9.25	30	7.71	8 8/9	5.11	11 1/3	6.52
Stern overhang	11 1/4	3.92	8 2/5	2.16	10	2.57	3 5/7	2.13	5 2/3	3.26
Keel	58 1/4	20.27	108	27.76	96	24.67	25 5/8	14.73	34	19.55
Flat	9	3.13	18	6.17	14	3.60	4	2.30	5 1/3	3.07
Run	9	3.13	12	3.08	15	3.86	3	1.72	6 2/3	3.83
Height from flat up to:	Deck		Deck		Deck		Deck		Naked beams	
1st level d./'naked' beams	9	3.13	16	4.11	15	3.86	4 1/2	2.57	4 1/2	2.59
Max. Breadth - waterline	15	5.22	24	6.17	20	5.14	6 2/3	3.85	7 1/2	4.31
2nd level - deck	15	5.22	27	6.94	22 1/2	5.78	7 1/2	4.29	8	4.60
3rd level - deck	22 1/2	7.83	36	9.25	29 1/2	7.58	10 1/2	6.02	11 1/2	6.61
Height between:										
1st and second levels	6	2.09	11	2.83	7 1/2	1.93	3	1.72	3 1/2	2.01
Max. Breadth & second level	0	0.00	3	0.77	2 1/2	0.64	3/4	0.44	1/2	0.29
2nd and third levels	7 1/2	2.61	9	2.31	7	1.80	3	1.73	3 1/2	2.01
Ratios										
Length/ keel	1.65		1.41		1.42		1.49		1.50	

(continued)

Table 7.4 (continued)

Ships	Sagri–1570 merchant ship	Oliveira 1580 18 *rumos* keel	Luis César 1589 16 *rumos* keel	San Juan 1565 whaling ship	García Palacio 1587 400-*ton*. Ship
Length/ breadth	3.21	2.99	3.16	2.91	3.19
Keel/ breadth	1.94	2.12	2.23	1.95	2.13
Stem overhang/ keel	0.46	0.33	0.31	0.35	0.33
Stern overhang/ keel	0.19	0.08	0.10	0.14	0.17
Depth of hold/ breadth	0.50	0.47	0.47	0.51	0.47
Depth at third level/ breadth	0.75	0.71	0.69	0.80	0.72
Run/depth at breadth	0.60	0.50	0.75	0.45	0.89
Flat/ breadth	0.30	0.35	0.33	0.30	0.33

de Palacio 1587, p. 90). Height from the ceiling planking up to the maximum breadth[20] and height from the ceiling planking up to the second deck.[21]

This way of measuring the height from the ceiling planking, above the floor timbers and not from the flat, was the official way to set the depth of hold. In 1590, it was included by Cristóbal de Barros in the *Cédula de Arqueamiento de Navíos* (Spanish gauge rule for ships) of that year. From this date onwards, the way in which this was done was officially formalised: from the ceiling planking to the maximum breadth, and not to the deck.

2.1.2 Vertical Distribution of Spaces

The horizontal divisions of a sixteenth century ship could be of two types:

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[20] 'Informe de Cristóbal de Barros sobre cómo han de ser los galeones a construir en Guarnizo y cómo eran los de Pero Menéndez de Avilés', 19 marzo 1581; MNM, Colección Navarrete, Tomo XXII, doc. 76, f° 292v° a 296v°; 'Relación del maestre Domingo de Bustrurria (...) en lo tocante a los arqueamientos de naos que se toman para el armada en esta costa de Biscaya...'. 1568. AGS, G. A., Legajo 347, n° 23, f°1–2; 'Cédula de Arqueamiento de Navíos', 1590. MNM, Colección Navarrete, T. I, N° de catálogo 789, f°169.

[21] Juan Cardona, 'Memorial que dio Juan de Cardona a su Majestad sobre los doce galeones que hacen en Santander y Bilbao. 24 febrero 589 GS.' 1589. AGS, Guerra Antigua, Legajo 245, f°11.

- Fixed decks and ‘naked’ beams. Fixed decks could be located below and above the waterline.
- ‘Naked’ beams were only located in the hold.

The ship described by Sagri did not have an orlop. She only had three fixed decks. The first of these was situated at a height of 9 *piè* from the flat, the second at 15 *piè,* and the third or upper deck at 22 ½ *piè*. On the other hand, the maximum breadth was situated at the height of the second deck and the maximum height of the waterline as well. The depth on the second deck was therefore 15 *piè*, which means that the first deck was at a height of 3/5 of the depth, leaving 2/5 between decks, i.e. 6 *piè*. The third deck, called *tolda*, was 7 ½ *piè* from the second one.

Oliveira states that the minimum distance between decks must be 7 *palms de goa* (1.80 m) which is the average height of a man, and a maximum of 10 *palmos*, because a man will find it more difficult to get up and down. Besides, with so much separation between decks, the ship will not be as strong. In this way, depending on their size, the ships could have one, two or three decks, and even have a first level with ‘naked’ beams in the case of the larger ones (Oliveira 1580, p. 127). Oliveira recommends setting the first deck at a height of one third of the keel. His criterion, therefore, is very different with that of Sagri.

In Spain, in the sixteenth century, the most common vertical distribution of the interior space of the ship consisted of a first deck below the waterline, called the orlop, and one or two more decks above the waterline, i.e. in the upper works. However, this distribution was sometimes modified by replacing the first deck with ‘naked’ beams, which fulfilled a structural function. The two upper decks were kept, the first of which was usually situated near the maximum breadth, a little higher or a little lower. The second deck, generally situated at a height of 3 or 3 1/2 *codos* (from 1.70 to 2 m) with respect to the first, was called the *puente*.

One of these two criteria was generally used to set the heights of the decks located below the waterline: In some cases, the dimensions of the goods to be transported were taken into account in order to optimise the loading capacity as much as possible. It was not the same to transport only wine barrels as to transport wool, nor was it the same to house troops in the orlop deck as to stow goods. In other cases, some pre-established rules were applied to the way the height was distributed.

2.1.3 Some Technical Characteristics

The Stem and the Fore Overhang In the shapes drawn by Sagri, overhangs are conditioned by the peculiar design of the stem. He states that he designed a new system using a tangent circumference to the bow end of the keel with a radius equal to the height of the upper edge of the bulwark, with respect to the flat. The result is that the maximum fore rake is located at the same height as the bulwark and its length is equal to the radius of the circumference, i.e. 27 ½ *piè.*

In the Iberian Atlantic area, this practice was completely unknown. Oliveira draws the stem with a keel length already defined. He sets the height of the *conves,* or upper deck, to one third of the keel. At the fore end of the keel, he traces a quarter of a circumference tangent to it, with a radius equal to the height of the *conves*, that is, one third of the keel (Oliveira 1580, p. 82). The resulting overhang at the height of the *conves* is equal to the radius of the circumference used, which is 1/3 of the keel, although he admits that the mentioned radius can be shortened by two *palmos* when it comes to a merchant ship. On his side, García de Palacio follows a procedure similar to that of Oliveira, using the third of the keel to determine the height of the upper deck and the fore overhang (García de Palacio 1587, p. 92).

The Stern Overhang Sagri establishes that for every *piè* of vertical height, there will be 1/2 *piè* of overhang. This is as much as saying that the stern overhang will be 1/2 of the bow's one. In this aspect, García de Palacio totally agrees with Sagri, but it should be noted that the drawing of the side elevation of the 400 *toneladas* ship that García de Palacio includes in his work does not conform to what is said in the text. On the contrary, Oliveira establishes the stern overhang at 1/4 of the fore's one.

The Flat Sagri gives two different versions. He says that it has to be 1/3 of the breadth or 3/5 of the depth, which is equivalent to 3/10 of the breadth. This detail must be taken into account so as not to confuse the reader, but for practical purposes we can say that it is the same as what all the Spanish authors of the time we have consulted indicate, that is to say 1/3 of the breadth.

Width of Decks Sagri states that the width of the first deck is equal to three times its height above the flat, and the width of the second deck is twice its depth. On the other hand, he does not give any information concerning the third deck. This layout differs from one of the Oliveira and García de Palacio. Oliveira is rather vague and states that the height on the *conves,* or upper deck, should be approximately 1/3 of the keel, while its width, or *boca*, should be a little more than its height. But then he gives the example of the ship with a keel of 18 *rumos* with a height in the *conves* of 6 *rumos* and a width, or *boca*, of 8 *rumos* (6 + 2) which is quite different (Oliveira 1580, p. 71). To obtain the width of the other two decks, it is necessary to use graphic interpretations.

García de Palacio is a somewhat different case, because he draws no deck below the waterline, but rather 'naked' beams. This reduces to two decks, which correspond to the second and third of Sagri (García de Palacio 1587, p. 90). To make things more complicated, the drawing of the master-frame shows that both decks have the same width, equal to half a maximum breadth. As in the case of Oliveira's designs, we must resort to graphic interpretations.

The Wales Sagri describes two wales that had a strong curvature: The first one had its centre at the level of the first deck. Its ends were at the same height as the second deck. The second wale had its centre at the level of the second deck and its ends did not rise as much as the first wale of the first deck. This means that the first wale was almost completely submerged.

García de Palacio's 400 *toneladas* ship had three wales. The first had a height of 10 *codos de vara* at mid-ship and 16 *codos* at its bow and stern ends. The second was placed half a *codo* higher, and the third other half a *codo* higher, i.e. a total height of 11 ½ *codos*, according to the author, although two pages before he said it was 11. The second deck, or upper deck, was placed at this height. Since the waterline was located at 7 ½ *codos* high, the first wale was located 2 ½ codos higher. It is difficult to imagine a situation more different from Sagri's *nave*.

On his side, Oliveira states that the wales should stick out two *dedos* from the planking and should have a square section. The first should be placed a little lower than the first deck. From there upwards, all those that fit up to the *conves*, three in three *palmos*. No wales were placed under the first deck (Oliveira 1580, p. 138). Since the first deck is 16 *palmos* away and the third is 36 *palmos* away, the wales are distributed over 20 *palmos*. This means that seven wales are placed. It is clear that the ship described by Oliveira has at least three wales below the waterline. This makes it much more similar to Sagri's ship than that of García de Palacio.

2.1.4 The Proportions of Sixteenth Century Merchant Ships in the Iberian Atlantic

Concerning the proportions, Sagri proposes the *As-Dos-Tres* rule in the version that takes the depth as one, the breadth as two, and the length as three. It does not mention the keel: It takes the depth measured from the flat to the second deck which is located precisely at the same height as the waterline (f°13). We will now examine how these proportions were treated in the Iberian context.

In Portugal, the basic dimension to which all the others referred was the keel. In Spain, Escalante de Mendoza also took the keel as the basis for his main proportions, which he thus established this way: every 5 *codos* of keel, 2 1/5 of breadth, and 7 of length (Escalante de Mendoza 1575, p. 22). This is equivalent to putting 2.3 *codos* of keel and 3.2 *codos* of length for every 1 *codo* of breadth, which represents a little more than the *As-Dos-Tres* rule. García de Palacio (1587) also took the keel as a reference and recommended that the depth should be a third of the keel and the breadth almost half of the keel (García de Palacio 1587, p. 90). On the other hand, the breadth was the reference dimension in the Bay of Biscay.

However, whatever is the dimension taken as a reference; there is no reason to modify the final proportions between them, which could be similar to those of other nautical areas. The significant point in the examples cited is that the keel appears as one of the main dimensions, which is not the case with the As-dos-Tres rule cited by Sagri. It was not until the seventeenth century that official regulations or standards appeared to regulate this kind of thing, but there were deeply rooted traditions in wide geographical areas. These traditions could have certain local particularities that differentiated the ships of a certain place from others in the same cultural area.

General Diego Brochero described the *As-Dos-Tres* rule in the same way as Sagri had done (Rodríguez Mendoza 2008).[22] Brochero served for a long time in the galley squadrons of Malta, Naples, and Sicily. Captain Thomé Cano defined the *As-Dos-Tres* rule in 1611 by stating that at 1 *codo* of breadth corresponds to 2 *codos* of keel and 3 *codos* of length. He added that the flat must be equal to 1/3 of the breadth and the depth equal to 3/4 of the breadth (Cano 1611, p. 15). The curious thing is that he claimed that this formula was the one used by all the Spanish, Italian, and masters of other nations. Sagri said the same by stating his rule, but it is evident that both rules do not say the same thing, far from it.

It is curious that before these two opposite versions of the *As-Dos*-Tres rule were exposed in 1570, Rodrigo de Vargas had already exposed a formulation that synthesised the two (Casado Soto 1988).[23] He defined the *As-Dos-Tres* rule by stating that at 30 *codos* of keel correspond 15 in breadth, 45 in length, and 7 ½ in depth. This suggests the idea that the statements of Sagri and Cano were adaptations to the local convenience of the more general rule set out by Rodrigo de Vargas.

In the Bay of Biscay, the proportion that related the depth to half a breadth was not used. Instead, the most suitable depth was chosen for each type of sailing or to optimise the load capacity in barrels. The first reference that we know about this point is given by the master Domingo de Busturia who explains the rule of ‘three to one’ for the merchant ships built in Biscay: for 1 *codo* of breadth, 3 of length, which coincides with Sagri.[24] But Busturia, in addition to stating the rule of ‘three to one’ for merchant ships, adds his opinion regarding the depth at the maximum breadth. According to him, a good proportion would be half a breadth plus a *codo* or *codo* and a half (f°2). This detail already reveals a fundamental characteristic of Cantabrian construction that distances it from the *As-Dos-Tres* rule applied by Sagri, which considers the depth to be *As*, making it equal to half a breadth.

We could quote more definitions from other authors stating the *As-Dos-Tres* rule, but they would not bring anything new. They are all interpretations on the same matter, where the magnitude that varies the most is the depth. These differences concern both its size and the way it is measured.

Usually, the dimension of the depth taken to apply the above-mentioned rule was the height of the maximum breadth or the deck that closed the hold. But we have to be very careful when interpreting the texts because when they quote the depth, without mentioning how far it is measured. Some authors place it at the maximum breadth, others at the deck and finally others at the upper deck. Taking into account all these documents, we find that the depth could be between 1/2 and 2/3 of the width. Everything seems to indicate that when the depth exceeds 2/3 of the breadth it means that it is measured up to the upper deck. This is the case of the depth

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[22] ‘Decreto del Consejo de guerra sobre los inclusos papeles que trajo el Señor Diego Brochero Anaya tocantes a la nueva ordenanza de navíos. 1607, 1613, 1618,’ AGS. Guerra y Marina, legajo 776 (8-10-1612), f°4.

[23] ‘Apuntamientos de Rodrigo de Vargas’. 1588. AGI, Real Patronato, leg. 260, 2°, r° 35.

[24] ‘Relación del maestre Domingo de Bustrurria (...) en lo tocante a los arqueamientos de naos que se toman para la armada en esta costa de Biscaya...’ 1568. AGS, G. A., Legajo 347, n° 23.

proposed by Thomé Cano as 3/4 of the breadth. Obviously, this way of measuring the depth is not useful to see if the proportions of the *As-Dos-Tres* rule are met or not. It is generally accepted that the depth should be calculated up to maximum breadth. However, the exact proportions are not found in any document that mentions a ship actually built.

As a summary we can say that in the last third of the sixteenth century Spain did not have any standardisation of proportions for merchant ships. Despite this, there were no major deviations from the *As-Dos-Tres* rule either, except in some Cantabrian ships and the Portuguese *naus da Índia*.

2.1.5 Comparative Table of Dimensions of Sagri's Ship Vs. Atlantic Ships

The Whaling Ship ***San Juan*** In 1978, a shipwreck was discovered in Red Bay (Canada), apparently corresponding to the Basque whaling ship *San Juan*, sunk in 1565. This very interesting ship was the object of a complete archaeological study whose results have been published by Parks Canada in a large 5 volume monograph from which we have obtained the data (Grenier et al. 2007, p. 27,29,54,57,59,143,153 vol. III). It should be noted that, in the monograph, the heights or depths are measured from the lower face of the keel, so to obtain the corresponding heights from the upper face of the keel, in our Table 7.4, 25 cm have been subtracted. On another subject, Brad Loewen and the archaeologists who studied her believe that this ship has a transversal shape with four arches, which brings her closer to the design of the Englishman Mary Rose.

Ship Described by García de Palacio García de Palacio explains to us in his *Instrucción Náutica* that the depth of a 400 *toneladas* boat should be 11.5 *codos de vara* or *castellanos* measured from the keel to the second deck or upper deck, being approximately 1/3 of the keel which was 34 *codos,* while the maximum breadth measured 16 (García de Palacio 1587, p. 90). This ship had a particular characteristic compared to most ships of the time: instead of having the first deck below the waterline, it had 'naked' beams in order to be able to stow barrels up to the first deck located 3 *codos* higher, as we have just seen. On the other hand, the text is accompanied by a drawing of a side elevation of the 400 *toneladas* ship, which shows the following approximate differences from the text: It was 48 *codos* length compared to 51 *codos* in the text. Her fore overhang was 8 *codos* compared to 11 1/3 *codos* in the text.

These differences are approximate because the drawing does not allow for precise dimensions. However, it is clear that with these dimensions the ratio length / breadth is 48 / 16 = 3 exactly. This incoherence, together with other minor ones, among figures quoted in different parts of the work, makes us to think that García de Palacio used information from different origins to document it. It could also be due to the fact that the author's original idea was to describe the ship of the drawing and then decided to add 3 *codos* to make her also suitable for war.

Ship Described by Oliveira In various passages of his *Livro da fábrica das naus*, Oliveira repeatedly refers to the *nau de 18 rumos of* keel which he considered to be a kind of representative prototype of the Portuguese sea-going ships industry. In this section we will follow the dimensions set out in the eighth chapter dedicated to merchant ships.

On page 70 of his work, Oliveira gives a somewhat imprecise explanation of what the proportions of the ships should be. According to him, the height of the *conves* or upper deck should be approximately equal to 1/3 of the keel or a little more, while the width or *boca* at the level of the *conves* should be a little greater than the height. The table shows the data provided by Oliveira, between text and drawings, on pages 71, 79, 81, 99, 124, and 125 of his cited work. Finally, on pages 128 and 129 he mentions the vertical distribution of the ship.

It should be remembered that Portuguese ships of this period usually had an orlop or first deck halfway between the flat and the beam, i.e. more or less in the same place as the Spanish ships had 'naked' beams. It is important to take this detail into account because it can generate confusion when talking about the first or second deck, because they do not mean the same thing to Spanish and Portuguese Treaties authors.

Ship Described by Luis César On November the 22th 1588, the King ordered Juan de Cardona, member of the Council of War, to build 12 galleons in the Bay of Biscay. Cardona consulted various experts. Among those who gave their opinions were Luis César, *Provedor dos Armazéns da Guiné, da Índia e das Armadas de Lisboa*. In a memorandum dated 10 January 1589, César sent to Cardona the specifications and measurements for the building of two types of galleons: one with 18 *rumos* keel and another with 16 *rumos*.[25] It should be noted that the measures provided by Luis César corresponded to ships that were actually being or had been built in Lisbon because he also offered to send a set of 'forms made', i.e. the templates needed for the construction.

2.1.6 Summary Table Comparing Data (Table 7.4)

Preparing a table of dimensions that have been taken in different ways requires a standardisation to make them comparable. In this case we unified two criteria:

- Heights are measured from the flat.
- Lengths are measured on the upper deck.

In the case of the ship described by Sagri, the ratio length / breadth appears to be slightly greater than 3. If the length had been expressed as measured on the second deck the ratio would be three exactly.

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[25] 'Relación que dio Luis César de las medidas y gálibo que han de llevar los doce galeones a fabricar por Juan de Cardona.' 1589. AGS, Guerra Antigua, Legajo 245, f°11[CH1], f°72 and 74.

We have prepared a table that summarises the data we have discussed above. To avoid problems of comparison in the table we quote levels as García de Palacio does, instead of decks. Doing it this way, the ‘naked’ beams will become the first level, the first deck will be the second level, and so on. This only affects the ship described by García de Palacio; in other ships the number of levels is the same as the number of decks.

In order to make a valid comparison, we have written down the length on the third deck in the summary table. Length / keel and length / breadth ratios of Sagri’s *nave* exceed those of the other ships which are compared with. In our opinion this is due to the method he used by to design the stem.

As far as depths at the maximum breadth are concerned, they all meet or come very close to the ratio of the *As-Dos-Tres* rule (depth = ½ of the breadth).

The distance separating the second level from the maximum breadth, or maximum limit of the waterline, varies between 0 cm on Sagri’s ship and the 64 cm on the one described by César (approximately 2 ½ *palmos de goa*).

Finally, the flat oscillates around 1/3 of the breadth in all of them.

2.1.7 The ‘*Nueva Fabrica*’ (‘New Shipbuilding’) of Juan de Veas and the Ordinances of the Beginning of the Seventeenth Century

At the beginning of the seventeenth century an important novelty in Spanish shipbuilding occurred: the almost total separation between design and production. This phenomenon was due to the publication of the first o*rdenanzas de fábricas* (Shipbuilding Ordinances) of 1607, 1613, and 1618 intended to regulate and standardise the construction activity.

This transforming task was promoted by General Brochero who relied on two of the best builders of the time: Captain Juan de Veas and Diego Ramírez: Veas, who was the Master Mayor of the Royal Factories in Guipúzcoa, an innovator who was applying a series of design improvements ranging from introducing the dead rising to adopting the flat equal to half a breadth. His way of doing things was set out by his contemporaries as the *nueva fábrica de Juan de Veas* (Cano 1611, p. 17, 49, 51) and his influence on the drafting of the new *ordenanzas* was decisive.

In 1607, there was an increase in length in relation to the maximum breadth. It was achieved by lengthening the keel, while maintaining the same overhang. In 1613, the length was reduced by reducing the keel and the overhang. In 1618, the length was again reduced by shortening the keel and the overhang.

We point out other important aspects of these *ordenanzas* related to the design and that include similar characteristics to Sagri’s *nave*: They introduce the dead rising; they limit the depth on the deck to half a breadth. It should be taken into account that the *As-Dos-Tres* rule prevailing in the Bay of Biscay did not establish a limit for the depth. With regard to the depth at the maximum breadth, it remains the same as the depth at the deck, except in 1618 when it descended by half a *codo*. Other characteristics that have a notable difference from Sagri’s *nave* are: The flat established at half breadth. A final aspect to be noted is that these Ordinances limit the number of decks to only two. The decks that in the sixteenth century went further below the waterline were replaced by 'naked' beams.

3 Tonnage Formulas as an Architectural Index in the Light of Nicolò Sagri's Manuscript

3.1 Generalities

Sagri devotes the entire Chap. 7 of his manuscript *Il Carteggiatore* to tonnage determination, explaining three formulas with different measure units. The aim of this study is to compare them with those used for Genoese, Portuguese, and Biscayne ships that – according to Sagri – had the same proportions of Ragusan ships. Before examining them, it is good to resume a few concepts about tonnage, a complex subject concerning sometimes volume, sometimes weight.

3.1.1 Tonnage as Volume: Gross and Net Tonnage

Gross and net tonnage (*Sp.: tonelaje o arqueo bruto/neto Fr.: tonnage ou jauge brute/nette, It.: stazza lorda/netta*) until a recent past were the sum, respectively, of all the enclosed volumes of a ship and of all the volumes were cargo could be stored. In early modern times, net tonnage was measured in different units according to the Country and the transported merchandise. Dry goods were bagged in sacks that could be stored leaving no empty space, so at full load their volume equalled the volume of the hold. For liquids it was different. They were transported in casks, called tuns (*toneles* in Portuguese and Spanish, *tonneaux* in French, *botti* in Italian) which left some empty space between them and among the ship timbers when stored in hold. The volume occupied was much more than the contained one and the measure unit used for net tonnage had to take account of the proportion between the two. Gross tonnage during the sixteenth century was not generally taken into account. In Spain only it was possible to find something similar to this concept, estimated through a percentage (20–25%) to add to net tonnage. It was expressed in *toneladas de sueldo,* and it took account of the volumes of dead works, i.e. between the second and the upper deck and inside the quarter-deck, as it is stated in a document of 1593.[26] In Great Britain, gross and net tonnage were later measured using an imperial unit, the ton burden or register ton of 100 cubic feet (2.83 m^3). In a recent past they became of worldwide use, and they were called gross register and net register tonnage. Since 1969 they are dimensionless indexes resulting from

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[26] 'Relación de la fábrica de doce galeones de guerra de la Escuadra Yllirica de Pedro de Ivella y Estéfano Dolisti. Carta de Pedro de Ivella al rey, de 17 diciembre 1593.' AGS, Guerra Antigua, Leg. 380–105, f°27.

complex mathematical formulas expressing the size, respectively, of a ship and her hold. Net tonnage of early modern ships is today more conveniently studied converting the original measure units into cubic metres.

3.1.2 Tonnage as Weight: Displacements Tonnage and Deadweight Tonnage

According to the Archimedes' principle, the weight of a ship equals the weight of the water she displaces, called displacement. It can be considered at different load conditions, the extremes being at full load and at ship unloaded, respectively, called full load displacement (*Sp.*: *desplazamiento máximo, Fr.: déplacement à pleine charge, It.: dislocamento a pieno carico*) and light displacement *(Sp.: desplazamiento en rosca, Fr.: déplacement lège*, *It.: dislocamento leggero*). The difference between them is called deadweight, and it can be considered with reference to the weight of the cargo only (net deadweight, *Sp.: porte neto*, *Fr.: port net, It.: portata netta*) or also to ballast, crew, passengers if any, provisions and ordnance (gross deadweight, *Sp.: porte bruto, Fr.: port en lourd, It.: portata lorda*). The maximum weight that a ship could carry was determined not only by the volume of her hold, but most of all by the limit to which her hull could be immersed to navigate safely (waterline). A cargo consisting only of high density materials would result in a hold with plenty of empty space while the ship had reached her highest waterline. If charged in proportion to its volume, such a cargo would provide little earning to ship's owners. Conversely, a cargo consisting only of low density materials would give little profit if charged by weight. The most profitable was to charge 'light' goods by volume and 'heavy' goods by weight. Of course there was a relation between the two physical quantities, and in the sixteenth century in Genoa it was considered 4 *cantari/salma*, corresponding to 0.72 t/m^3 (see paragraph 7.3.5). Historical sources give no elements on the displacement of Renaissance ships, and very little of those of the seventeenth century. According to Fournier's *Hydrographie* of 1643 and to the Dutch Witsen that in 1671 quoted him, a ship could carry as much cargo as her own weight: in today's terms, her net deadweight was equal to her light displacement (Fournier 1643, p. 780; Hoving et al. 2012, p. 20). To obtain full load displacement, the weight of ballast, crew, passengers if any, provisions and ordnance must be added to net deadweight and light displacement. In this study, the term 'tonnage' has been used only with general reference, including both volume and weight; otherwise, it has been specified whether net/gross tonnage or net/gross deadweight is concerned.

3.1.3 Block Coefficient and Its Relation with Ship Proportions

The proportion between the volume of the immersed hull (or the displaced water) and the volume of the parallelepiped circumscribed to it, is called block coefficient. It is a dimensionless quantity expressing the fullness of forms: the higher the block coefficient, the bulkier the hull. It is important to remark that ships with the same proportions can have different block coefficients: the bulkier keeping her main cross-section almost unvaried in a long, central part of the hull, then tapering near stern and bow (high block coefficient), the slimmer immediately tapering from the main cross-section towards the extremities (low block coefficient). For this reason, it is an important architectural index to be studied together with ship proportions.

3.1.4 Formulas, Method of Study and 'Block Coefficient of the Hold'

Since the Renaissance, instructions to determine tonnage were given in plain words, then giving a practical example; expressing them in formulas is a more recent habit. It is important to remark that, when net tonnage was considered, dimensions and volume were never expressed in the same units, like *piè* and cubic *piè*, so formulas included, in a more or less evident way, a measure conversion factor. When the result was net deadweight as in the case of some Genoese ships, a 'weight to volume' coefficient too had to be present. To date formulas have been studied solving all the operations described, which is correct from a mathematical point of view, but it does not help in comparing them. In this chapter, with reference to experimental sciences, formulas are written including measure units of both dimensions and coefficients, in order to verify their coherence and to make evident whether they are about volume or weight. In order to make a comparison, it is necessary to eliminate all the conversion factors by transforming all measures in the same units, such as metres and cubic metres. When deadweight is concerned, early modern weight units are converted into (metric) tons of 1000 kg. Most of the studied formulas, like Sagri's ones, can be reduced to a form in which net tonnage (NT) equals the product of the ship's principal dimensions (Length of hold by maximum Breadth by Depth of hold) multiplied by a coefficient:

$$\mathrm{NT} = \mathrm{L} \cdot \mathrm{B} \cdot \mathrm{D} \cdot \mathrm{c}.$$

Generally, measures are taken at the height of the widest point of the hull (maximum breadth), coinciding with the waterline at full load. This coefficient can be expressed as the net tonnage (the volume of the hold) divided by the volume of the parallelepiped circumscribed to it. It is similar to the above-mentioned block coefficient of the ship, but it is referred to her interior volume, and since now I will call it 'block coefficient of hold' (bch):

$$\underline{\mathrm{bch} = \mathrm{NT} / \left(\mathrm{L} \cdot \mathrm{B} \cdot \mathrm{D}\right)}$$

The former is measured outside the hull up to the waterline at full load, the latter inside the hull to an upper limit that generally coincided with maximum breadth/waterline. The difference between the two is mainly due to the thickness of the hull. Though not being identical, both the coefficients can be considered indicative for the fullness of forms of ships.

3.1.5 The 5% Reduction, or 0.95 Factor

In three out of the six examined formulas for net tonnage is present a reduction of 5%, that can be expressed as a 0.95 factor. The first to write of it was the Spanish Busturia in 1568, followed by Sagri in 1571. In Spain the last were Thomé Cano in 1611 and the *Ordenanzas* of 1613 and 1618. In Eastern Mediterranean the Ragusan Ohmucevic was the last circa 1661, stating that with the new formulas it was not necessary any more. Spanish authors explained it with the necessity of taking account of the taper of the hull towards stern and bow and to the room occupied by well pumps; nevertheless the mentioned *Ordenanzas* gave no explanation for it. Sagri was the author who more detailed it, considering a reduction from 3% to 10% according to the presence of partitions inside the hold and to a more or less flat bottom in the hull. In his opinion, a 5% reduction was appropriate for most ships. Crescentio and Ohmucevic referred to the same 5% reduction due to the above-mentioned partitions (Crescentio 1602, pp. 69–70).

3.2 Sagri's Formulas for Net Tonnage

In Chap. 7 of his manuscript, Sagri exposes three formulas to determine net tonnage (that he calls *portata*), adapted to different measure units: for length *piedi* (or *piè*) of Venice and *chobitti* (allegedly common in Western Mediterranean), for volume *carri* of Naples and *salme generali* of Sicily, both common in Italy and Dalmatia. Sagri's formulas only deal with volume; no reference is made to the weight that a ship could carry. Ships were measured at the widest point of the hull, coinciding with the waterline at full load, the height of the second deck (out of three), the top of the hold, and also the highest level of the cargo when it consisted in wheat only. The dimensions considered by Sagri were: length (L) at the second deck, maximum breadth (B), and depth of hold (D), the latter measured from the upper face of the keel (f°16 V–20 V). Sagri's formula can be reduced to the product of the three principal dimensions of the ship multiplied by a factor that, after converting all measures into a single unit, is the block coefficient of the hold (bch):

$$\mathrm{NT} = \mathrm{L}\cdot\mathrm{B}\cdot\mathrm{D}\cdot\mathrm{c}$$
$$\mathrm{c} = \mathrm{NT}/\left(\mathrm{L}\cdot\mathrm{B}\cdot\mathrm{D}\right) = \mathrm{bch}$$

The reference merchandise were grains (usually wheat) bagged in sacks that could be stored leaving no empty space, so there was no need to take account of the difference between the volume contained and the space occupied by containers, as it was for casks and barrels. In this case the transported volume coincided with the volume of the hold.

3.2.1 Sagri's First Formula for Net Tonnage (*Piedi* to *Salme*)

Net tonnage, expressed in *salme generali di Sicilia* (sgS), results from the product of the three main dimensions of the ship expressed in *piedi di Venezia* (pV, Venetian feet of 0.3477 m), then subtracting one third from the result (i.e. multiplying by two thirds), subtracting again 5% of the new result (i.e. multiplying by 0.95), and finally dividing by ten:

$$\mathrm{NT}_{[\mathrm{sgS}]} = \left[\left(\mathrm{L}_{[\mathrm{pV}]} \cdot \mathrm{B}_{[\mathrm{pV}]} \cdot \mathrm{D}_{[\mathrm{pV}]} \cdot 2/3\right) - 5\%\right] / 10_{[\mathrm{sgS/pV}^3]} = \mathrm{L}_{[\mathrm{pV}]} \cdot \mathrm{B}_{[\mathrm{pV}]} \cdot \mathrm{D}_{[\mathrm{pV}]} \cdot 0.0633_{[\mathrm{sgS/pV}^3]}$$

Converting into metres, according to early modern equivalence 1 *carro* = 7 *salme* (1 *salma* = 0.2845 m^3), the block coefficient of hold is 0.429:

$$\mathrm{NT}_{[\mathrm{m}^3]} = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[E]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.0633_{[\mathrm{sgS/pV}^3]} \cdot 0.2845_{[\mathrm{m}^3/\mathrm{sgS}]} / 0.3477^3_{[\mathrm{m}^3/\mathrm{pV}^3]} =$$

$$= \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.429$$

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} / \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 0.429$$

Today's metrology has established the equivalence 1 *carro* = 7.5 *salme* (1 *salma* = 0.2655 m^3) (DELL'OSA, 2010, 7), in this way the block coefficient of the hold becomes 0.400:

$$\mathrm{NT}_{[\mathrm{m}^3]} = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.0633_{[\mathrm{sgS/pV}^3]} \cdot 0.2655_{[\mathrm{m}^3/\mathrm{sgS}]} / 0.3477^3_{[\mathrm{m}^3/\mathrm{pV}^3]} =$$

$$= \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.400$$

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} / \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 0.400$$

3.2.2 Sagri's Second Formula for Net Tonnage (*Piedi* to *Carri*)

Net tonnage, expressed in *carri di Napoli* (cN) of 1.9915 m^3, results from the product of the three principal dimensions of the ship expressed in *piedi di Venezia* (pV), then subtracting 10% (i.e. multiplying by 0.9) and dividing by 100:

$$\mathrm{NT}_{[\mathrm{cN}]} = \mathrm{L}_{[\mathrm{pV}]} \cdot \mathrm{B}_{[\mathrm{pV}]} \cdot \mathrm{D}_{[\mathrm{pV}]} \cdot 0.9 / 100_{[\mathrm{cN/pV}^3]} = \mathrm{L}_{[\mathrm{pV}]} \cdot \mathrm{B}_{[\mathrm{pV}]} \cdot \mathrm{D}_{[\mathrm{pV}]} \cdot 0.009_{[\mathrm{cN/pV}^3]}$$

Converting the formula into metres, the block coefficient of the hold is 0.426.

$$\mathrm{NT}_{[\mathrm{m}^3]} = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.009_{[\mathrm{cN/pV}^3]} \cdot 1.9915_{[\mathrm{m}^3/\mathrm{cN}]} / 0.3477^3{}_{[\mathrm{m}^3/\mathrm{pV}^3]} =$$
$$= \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.426$$

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} / \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 0.426$$

3.2.3 Sagri's Third Formula for Net Tonnage (*Chobitti* to *Salme*)

Sagri states that the last formula considers the units used to measure ships outside of Venice, in Western Mediterranean, Italy, and Spain: the *chobitti* (cbt) of three *palmi di canna* each. Net tonnage, expressed in *salme generali di Sicilia* (sgS), results from the product of the three principal dimensions of the ship, subtracting one fourth (i.e. multiplying by three fourth, or 0.75) then subtracting again 5%:

$$\mathrm{NT}_{[\mathrm{sgS}]} = \mathrm{L}_{[\mathrm{cbt}]} \cdot \mathrm{B}_{[\mathrm{cbt}]} \cdot \mathrm{D}_{[\mathrm{cbt}]} \cdot 0{,}75_{[\mathrm{sgS/cbt}^3]} \cdot 0.95 = \mathrm{L}_{[\mathrm{cbt}]} \cdot \mathrm{B}_{[\mathrm{cbt}]} \cdot \mathrm{D}_{[\mathrm{cbt}]} \cdot$$
$$0.7125_{[\mathrm{sgS/cbt}^3]}$$

Converting the formula into metres, according to the early modern equivalence 1 *carro* = 7 *salme* (1 *salma* = 0.2845 m^3), and to the one stated by Sagri 1 *chobitto* = 2.25 *piedi di Venezia* (= 0.7823 m), the block coefficient of hold becomes 0.423:

$$\mathrm{NT}_{[\mathrm{m}^3]} = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.7125_{[\mathrm{sgS/cbt}^3]} \cdot 0.2845_{[\mathrm{m}^3/\mathrm{sgS}]} / 0.7823^3{}_{[\mathrm{m}^3/\mathrm{cbt}^3]} =$$
$$= \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.423$$

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} / \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 0.423$$

Today's metrology has determined the correct equivalences: 1 *carro* = 7.5 *salme* (1 *salma* = 0.2655 m^3) and 1 *chobitto* = 0.7432 m (DELL'OSA 2010, 7).

$$\mathrm{NT}_{[\mathrm{m}^3]} = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.7125_{[\mathrm{slm/cbt}^3]} \cdot 0.2655_{[\mathrm{m}^3/\mathrm{slm}]} / 0.7432^3{}_{[\mathrm{m}^3/\mathrm{cbt}^3]} =$$
$$= \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.461$$

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} / \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 0.461$$

Due to inaccuracy of early modern conversion factors, the block coefficient of the hold obtained with Sagri's third formula (0.423) was 9% smaller than the correct one (0.461).

3.2.4 The Application of Sagri's Formulas

Sagri provides an example of the application of each formula to a ship of 90 x 30 x 15 *piedi di Venezia* (31.3 × 10.4 × 5.2 m, length x breadth x depth of hold), or 40 x $13^1/_3$ x $6^2/_3$ *chobitti*, stating the equivalence he gives 1 *chobitto* = 2.25 *piedi*. He gives the resulting net tonnage of the three formulas: respectively 2565, 2548 and 2534 *salme* (the second one converted from *carri*). According to Sagri, these differences were irrelevant compared to such huge quantities, the results of the first and third formulas being +0.7% and − 0.5% of the second one. The three block coefficients of hold, considering the equivalences proposed by Sagri, fall very near: 0.429, 0.426, and 0.423 (average 0.426). Actually, once corrected according to today's metrology, the first and third formulas are more divergent: 0.400 and 0.461, with a difference of −7% and + 9% compared to average 0.429. The block coefficient of hold resulting from the second formula (0.426, like the average of the original coefficients) is the only one not to be affected by the inaccuracy of the equivalences and is also almost identical to the average of the corrected ones.

3.2.5 The Survival of Sagri's Third Formula in the Seventeenth Century

Bartolomeo Crescentio, a Roman engineer, published in 1602 a treatise entitled *Della nautica mediterranea*, often quoting the manuscript *Il Carteggiatore*, and exposing Sagri's first formula with the same example of a *nave* of 90 × 30 × 15 *passi* and the same equivalence of 1 *carro* = 7 *salme*, instead of 7.5 as established by today's metrology (Crescentio 1602, pp. 69–70). Circa 1661, 90 years after the death of Nicolò Sagri, the Ragusan mathematician Petar Damjan Ohmucevic wrote a manuscript dealing with fractions and extraction of second and third roots, with a method to calculate ships' tonnage. An excerpt of it, with the title '*Del modo di mesurare, o archiare le navi di qualsivoglia genere e forma, e riduli con detto archiamento alla giusta portata di tanti carra di tomola trentasei l'uno*'.[27] is conserved in the Dubrovnik Historical Archives. Before explaining his own original method to determine ships' tonnage, forerunning the application of integral calculus, he described Sagri's first formula as the most used of his time. He gave the same example of a ship 90 × 30 × 15 *piedi di Venezia*, expressing net tonnage in *salme generali di Sicilia,* then converting it to *carri di Napoli*, according to the same factor 1 *carro* = 7 *salme.* Ohmucevic added that this formula was widely used in the Mediterranean area, from the Levant to Barcelona, through Venice and the entire

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[27] I am grateful to Divo Basic for communicating me the transcription of this document.

Adriatic coast. In his opinion, this method had worked well until ships had been built in the old way, but at his time their design had changed too much and the use of that formula resulted too far away from reality (Sisevic 1952). An incoherence exists: Ohmucevic stated that the formula he described, the same as Sagri's first one, made for Venetian *passi*, was used throughout almost the whole Mediterranean area, including Venice and the Adriatic Sea; Sagri explained that in his third formula measures were expressed in *gobiti*, a unit that – according to his statement – was used outside of Venice, being common in the Western Mediterranean, in particular Spain and Italy.

3.3 Tonnage Determination in Spain in the Sixteenth Century

During the sixteenth century in Spain ships' dimensions were expressed using two different units, the *codo castellano* of 0.557 and the *codo de ribera* of 0.575 m. Net tonnage was measured as the number of casks called *pipas andaluzas* or *de Sevilla* that a ship could carry. The space occupied by two *pipas* was a *tonel* of eight cubic *codos*, but it had two different estimates: the *tonel castellano* or *tonelada de carga* was eight cubic *codos castellanos*, corresponding to 1.382 m^3, the *tonel macho* was eight cubic *codos de ribera*, or 1.521 m^3. In Northern Spain the *codo de ribera* was used, while in Andalusia both the *codos* were used, with a prevalence of the *castellano.*

3.3.1 Tonnage Determination in Spain in the First Half of Sixteenth Century

Since the late fifteenth throughout the first half of the following century in Spain is documented an empirical method to determine net tonnage, based on the use of hoops and gauges to estimate how many casks could be contained inside the hold. A professional figure existed, the *arqueador*, an officer charged to determine tonnage. It is believed that mathematical formulas based on ship's dimensions existed together with empirical methods, becoming of general use before the mid-sixteenth century (Casado Soto 1988, pp. 73–77). Evidence for this assessment is not strong, as it is possible to verify in the following examples. The net tonnage of a *nao* named '*Trinidad'*, property of Ochoa Sáez de Goronda from Bilbao, examined in 1523 in Portugalete by the inspector Juan Nicolás de Areita was declared 190 unspecified *toneles,* but the method used is unknown. The ship had the following dimensions (in unspecified *codos*): length of the hold 41¼, keel 30, maximum breadth 13, depth of hold 6 (Guiard y Larrauri and Basas Fernández 1968, p. 76). Applying Spanish tonnage formulas of the sixteenth century, the best result is given by the Busturia's (1568) and Barros' (1580) one, at 191 *toneles* (Hormaechea et al. 2018, pp. 162–168). Probably this is the reason why it has been recently assumed that the Busturia's and Barros' formula was already used in 1523 (Castro 2013, p. 1139; Casabán et al.

2014, p. 570). Nevertheless, there is no evidence allowing to exclude that Arteita had used an empirical approach converging to the same result of the later formulas. Another document written in Sevilla in 1552 refers of the tonnage determination of four Spanish ships, whose capacity was defined by the number of small casks (*pipas*) that could be contained in different parts of the hold, the result divided by two to obtain the number of *toneles machos* of 1.521 m^3 (considering a *tonel* the volume occupied by two *pipas*), then 20–25% was added to obtain the *toneladas de sueldo*. The use of *toneles machos* in Andalusia contradicts the current belief that in that region only *toneles castellanos*, i.e. *toneladas de carga* of 1.382 m^3 were used. The four ships were loaned by the Crown for the *armada* and had no cargo, so *pipas* could not have been counted after they had been loaded, and for this reason it has been considered that a mathematical method had to be used (Casado Soto 1988, pp. 78–80, 261). Actually using hoops and gauges it was possible to estimate the amount of *pipas* that could have been contained in each part of the hold and in this case too there is no sure evidence that a mathematical method had been used. The three earliest Spanish tonnage formulas known are almost coeval, dating to the years 1560–1575, and probably they were in use at the same time.

3.3.2 The Presidente-Visitador's Formula (c.1560–1570)

This formula is known through an undated Spanish document written by a *visitador*, an officer of the *Casa de la Contratación* charged to inspect ships. Casado Soto (1988), the first who published it, attributed it to the 60s of the sixteenth century in his text, but he wrote c.1560 in a caption as well as in the appendix, and only the latter date was reported by the authors that dealt with this subject after him. The document contained no geographical indication about where it had been written. Ship's measurements were given in *codos mayores* (*codos de ribera* de 33 dedos), and tonnage in unspecified *toneles* (to be intended as *machos*, since the kind of *codos*), with the approximated equivalent *toneladas de sueldo* (Casado Soto 1988, pp. 90, 82, 265–270). Some later authors have inexplicably reported that the Presidente-Visitador's formula was used in the region of Cadiz-Sevilla and that measurements were given in *codos castellanos* and *toneladas de carga* (Castro 2013, p. 1139; Casabán et al. 2014, p. 570). Besides describing the formula, the document gives dimensions and net tonnage of some ships. The first one is a 300 *toneles nao* built to serve in the *armada* as a coast guard. Her keel is 32 *codos*, the length of the hold 48 or 49, the maximum breadth 15, the depth of hold 7.5, and the upper deck 3.5 *codos* higher. The last ship is a smaller one of unspecified use, and is given as an example of the calculations of the tonnage formula. Her keel is 20 *codos*, the length of her hold is not given, her maximum breadth 10 *codos*, her depth of hold 8 *codos* (Hormaechea et al. 2018, p. 163). According to the Presidente-Visitador, net tonnage was the result of the product of the length of the keel, the maximum breadth and the depth of hold, multiplied by two thirds:

$$NT_{[cdr^3]} = K_{[cdr]} \cdot B_{[cdr]} \cdot D_{[cdr]} \cdot 2/3 = K_{[cdr]} \cdot B_{[cdr]} \cdot D_{[cdr]} \cdot 0.667$$

The conversion into metres by multiplying every dimension by the factor 0.575 m/cdr, produce no changes in the formula, as only one measure unit was present:

$$NT_{[m^3]} = K_{[m]} \cdot B_{[m]} \cdot D_{[m]} \cdot 2/3 = K_{[m]} \cdot B_{[m]} \cdot D_{[m]} \cdot 0.667$$

Inserting the measures of the first ship mentioned in the document, the right tonnage of 300 *toneles* can be obtained considering the depth of hold equivalent to half the beam, then dividing by eight. Substituting the ratio ‘keel to length’ (2/3, or 0.666) of the first ship taken as an example by the Presidente-Visitador, into his own formula, the resulting block coefficient of hold is 0.444:

$$NT_{[m^3]} = 2/3\,L_{[m]} \cdot B_{[m]} \cdot D_{[m]} \cdot 2/3 = L_{[m]} \cdot B_{[m]} \cdot D_{[m]} \cdot 0.444$$

$$bch = NT_{[m^3]} / \left(L_{[m]} \cdot B_{[m]} \cdot D_{[m]}\right) = 0.444$$

It is possible to apply this formula to a ship with the proportions of the *nave* described by Sagri, where K = $1+{}^{15}/_{16}$ B, (obtained by subtracting the overhangs from the length), and B = 1/3 L, so K = 31/48 L. By substituting this equivalence into the Presidente-Visitador’s formula, the block coefficient of hold becomes 0.431:

$$NT_{[m^3]} = 1^{15}/_{16}/3\,L_{[m]} \cdot B_{[m]} \cdot D_{[m]} \cdot 2/3 = L_{[m]} \cdot B_{[m]} \cdot D_{[m]} \cdot 0.431$$

$$bch = NT_{[m^3]} / \left(L_{[m]} \cdot B_{[m]} \cdot D_{[m]}\right) = 0.431$$

only 1% and 0.5% more than the average of Sagri’s coefficients, 0.426 and 0.429, respectively, before and after correcting the equivalence *carri* to *salme*.

3.3.3 Captain Rodrigo Vargas’ Formula (c.1565–1575)

Captain Rodrigo Vargas worked as *arqueador* in Sanlúcar, at the mouth of river Guadalquivír in Atlantic Andalucía, in the period 1565–1575. According to the formula he used, net tonnage was calculated by multiplying the length of the hold by the squared semi-sum of depth of hold and half the breadth, the result divided by eight to obtain *toneles machos* from cubic *codos* (to be intended as *de ribera*, since the use of *toneles machos*). While the published document openly mentions *toneles machos*, it has sometimes been reported as mentioning *codos castellanos* and *toneladas de carga* (Casabán et al. 2014, p. 570). Depth of hold seems to be measured at the second deck (out of three), situated half a *codo* or one *codo* higher than half the maximum breadth in the examples given by Vargas: 8 *codos* for a breadth of 15, or 9 *codos* for a breadth of 16 (Casado Soto 1988, pp. 81–84, 271–274):

$$NT_{[\mathrm{tnlM}]} = L_{[\mathrm{cdr}]} \cdot \left[\left(B_{[\mathrm{cdr}]} / 2 + D_{[\mathrm{cdr}]}\right) / 2\right]^2 / 8_{[\mathrm{cdr}^3/\mathrm{tnlM}]}$$

Converting to metric decimal units:

$$NT_{[\mathrm{m}^3]} = L_{[\mathrm{m}]} \cdot \left[\left(B_{[\mathrm{m}]} / 2 + D_{[\mathrm{m}]}\right) / 2\right]^2$$

If we substitute in Vargas' formula the proportion between depth of hold and maximum breadth of the first ship he gives as example, i.e. D = 8/15 B.

$$NT = L \cdot \left[\left(B / 2 + 8 / 15B\right) / 2\right]^2 = L \cdot \left(31 / 30B\right)^2 / 4 = L \cdot 961 / 900B^2 / 4 = L \cdot B^2 \cdot 0.267$$

Then, substituting the reversed proportion B = 15/8 D the resulting block coefficient of hold is 0.501:

$$NT = L \cdot B \cdot \left(15 / 8D\right) \cdot 0.267 = L \cdot B \cdot D \cdot 0.501$$

$$bch = NT_{[\mathrm{m}^3]} / \left(L_{[\mathrm{m}]} \cdot B_{[\mathrm{m}]} \cdot D_{[\mathrm{m}]}\right) = 0.501$$

Using the proportion of the second ship mentioned by Vargas (D = 9/16 B), the block coefficient of hold would be 0.502.

For ships whose depth of hold equals half the maximum breadth (D = B/2), like those described by Sagri, the formula becomes:

$$NT_{[\mathrm{m}^3]} = L_{[\mathrm{m}]} \cdot \left[\left(B_{[\mathrm{m}]} / 2 + B_{[\mathrm{m}]} / 2\right) / 2\right]^2 = L_{[\mathrm{m}]} \cdot B^2_{[\mathrm{m}^2]} / 4$$

and, after substituting the reversed proportion B = 2 D, the block coefficient of hold becomes 0.500:

$$NT_{[\mathrm{m}^3]} = L_{[\mathrm{m}]} \cdot B_{[\mathrm{m}]} \cdot 2D_{[\mathrm{m}]} / 4 = L_{[\mathrm{m}]} \cdot B_{[\mathrm{m}]} \cdot D_{[\mathrm{m}]} / 2 = L_{[\mathrm{m}]} \cdot B_{[\mathrm{m}]} \cdot D_{[\mathrm{m}]} \cdot 0.500$$

In the three examined cases the coefficients of Vargas' formula diverge very little, just 0.2% from the average 0.501. Ships with a depth of hold D = 5/8 or 3/4 of the maximum breadth (like a depth of hold of 10 or 12 *codos* instead of 9 as in Vargas' example, for a breadth of 16 *codos*) would have a higher coefficient of respectively 1.25% or 4%. The complexity of Vargas' formula gives relevant differences only when the depth of hold is three quarters of the breadth or more, otherwise the results are very similar to those of the simple product of the three dimensions divided by two.

3.3.4 The Busturia's and Barros' Formula (Busturia, 1568; Barros, 1580; Real Cédula, 1590)

Domingo de Busturia was the first to differentiate the tonnage of warships and merchantmen, and the latter between old and new design (*arte vieja* and *arte nueva*). He explained where measurements had to be taken: the breadth at the widest point, the depth from the maximum breadth to the floor (*soler*, not to the flat of the floor, or *plan*), the length over the first deck. Net tonnage is the result of the sum of half the breadth plus the depth of hold, divided by two and raised to the square, then multiplied by the length of hold, and finally multiplied by 0.95 and divided by 8, the conversion factor from *codos de ribeira* to *toneles machos*, the units in which measurements are expressed (Hormaechea et al. 2018, pp. 164–165):

$$NT_{[\mathrm{tnlM}]} = L_{[\mathrm{cdr}]} \cdot \left[\left(B_{[\mathrm{cdr}]} / 2 + D_{[\mathrm{cdr}]}\right) / 2\right]^2 \cdot 0.95 / 8_{[\mathrm{cdr}^3/\mathrm{tnlM}]}$$

Cristobal de Barros, an *arqueador* working in Cantabria, in Northern Spain, since 1563, wrote a document in 1580 describing the method he used to determine tonnage, the same as Busturia's. He also explained the way to take measurements, adding that the length had to be taken at the same height where maximum breadth and depth of hold were taken (Casado Soto 1988, pp. 84–88, 287–291). The same situation described by Sagri, as we have seen, that corresponds also to waterline. By da en san Lorenzo el 20 de agosto de 1590. M.N.M. Collecion Navarrette, N° de catalogo 789 of 1590, the use of this formula, together with the measure units concerned (the *codos de ribera* of 33 *dedos* and the *tonel macho* of 8 cubic *codos de ribera*) were imposed to the whole Spain. The use of this formula survived little beyond the end of the sixteenth century, being considered in the *Reales Ordenanzas* of 1607 and 1618. The formula was the same as Vargas', with just the adding of a reduction of 5%, the above-mentioned 0.95 coefficient (Casado Soto 1988, pp. 289–291; Hormaechea et al. 2018, p. 169). The block coefficients of the hold became 0.476 and 0.477 in the two Vargas' examples (D = 5/8 B and D = 9/16 B), and 0.475 when D = 1/2 B; in other words 0.476 ± 0,2%. Relevant differences seem to exist only for ships with particularly deep or shallow drafts, as it has been already commented about Vargas' formula.

3.4 *Tonnage in Portugal in the Sixteenth Century*

During the sixteenth century in Portugal tonnage was determined in the traditional empiric way using hoops and gauges. In his manuscript *Ars Nautica* of circa 1570, Fernando Oliveira explained a method consisting in the sum of the *tonéis* that could be stored in each *rumo* of length of the keel. The *rumo* was a measure unit equivalent to 1.54 m, corresponding to the major dimension of a *tonel*, so the method he was describing could be the 'hoops and gauges' one. In his later manuscript *Livro da fabrica as naus* of circa 1580, Oliveira explained that a *nau* with an 18 *rumos* keel could store 64 *tonéis* in her main cross-section, but this capacity was decreasing in the other *rumos* of the keel length, because of the rising and the narrowing of the hull. According to him, instead of the 'over 1000 *tonéis*' resulting from the multiplication of the 64 by the 18 that could be stored in the keel length, the ship could carry no more than 600. Oliveira did not propose any mathematical solution to this problem (Castro 2013, p. 1138). No formula is known to have been used throughout the sixteenth century to at least 1612, when a Spanish document referred that the 'hoops and gauges' empirical method was still in use in Portugal. Nevertheless shipwrights were aware of the relation between ship dimensions and net tonnage, and tables existed relating the latter to the length of the keel. F. Contente Domingues proposed a formula explaining the relation between net tonnage and keel length, which does not imply that it was known and used in the sixteenth century. It considers the length of the Keel in *rumos* (rm), the maximum Breadth and the Depth of hold in *palmos de goa* (pdg), and the resulting net tonnage in Portuguese *toneladas* (Hormaechea et al. 2018, p. 184)*:*

$$NT_{[\text{tnldP}]} = K_{[\text{rm}]} \cdot B_{[\text{pdg}]} \cdot D_{[\text{pdg}]} / 20_{[\text{rm}\cdot\text{pdg}^2/\text{tnldP}]} = K_{[\text{rm}]} \bullet B_{[\text{pdg}]} \cdot D_{[\text{pdg}]} \cdot 0.05_{[\text{tnldP}/\text{rm}/\text{pdg}^2]}$$

or, converting the measure of the keel from *rumos* into *palmos de goa*:

$$NT_{[\text{tnldP}]} = K_{[\text{pdg}]} \cdot B_{[\text{pdg}]} \cdot D_{[\text{pdg}]} / 120_{[\text{pdg}^3/\text{tnldP}]} = K_{[\text{pdg}]} \cdot B_{[\text{pdg}]} \cdot D_{[\text{pdg}]} \cdot 0.008(3)_{[\text{tnldP}/\text{pdg}^3]}$$

The vertical dimension used in Portugal to determine tonnage in the sixteenth century was measured up to the first deck instead of the level of maximum breadth/waterline, and there was no fixed proportion between the two heights (Hormaechea et al. 2018, p. 185). For these reasons, it is not possible to convert the formula proposed by F. Contente Domingues to the height of maximum breadth/waterline to study the block coefficient of hold in a general way.

3.5 Tonnage in Genoa in the Sixteenth Century

No nautical treatise has been left by Genoese seamen or shipwrights, possibly in an attempt to preserve secrecy. Alternatives sources for Genoese shipbuilding are notarial records, as sometimes they mention data about ships' dimensions and tonnage. Many construction contracts of Genoese ships have been published, in which tonnage was measured sometimes as a weight expressed in *cantari* of Genoa (cG), sometimes as a volume expressed in *mine* or in *salme generali* of Sicily (sgS). The equivalence was 1 *salma* = 2.5 *mine* before 1550, and 2.37 *mine* after that date. The tonnage of a same ship could be expressed as net tonnage in *salme* in some document and as net deadweight in *cantari* in some other. A 'weight to volume' conversion coefficient existed, allowing to transform net tonnage into net deadweight, according to the formula $NT_{[sgS]} = NDW_{[cG]} / 4_{[cG/sgS]}$.[28] Converted into the metric system, the coefficient 4 *cantari/salma* corresponds to 0.72 t/m^3, very near to the average density of wheat, 0.75 t/m^3. Liquids carried on ships were measured in *botti:* their capacity is not known, but two equivalences existed, 10 *cantari/botte* and 0.4 *botti/salma* (Borghesi and Calegari 1970, pp. 101–102; Gatti 1975, pp. 35–36). Such a measure unit did not exist in Genoa, where the largest containers for liquids were the *barile* and *metreta*, which capacity grew continuously during the sixteenth century, never exceeding, respectively, 0.078 m^3 and 0.156 m^3 (ROCCA, 1871: 81–2). From the first mentioned equivalence it is evident that every *botte* weighed 10 *cantari* of Genoa, or 476.5 kg, and from the second that it corresponded to 2.5 *salme generali* of Sicily, or 0.664 m^3, a volume too large to match the above-mentioned weight. The only possibility is that such volume, instead of the capacity, was the space occupied in the hold that also included the empty room between *botti* and among ship's timbers. Considering that the weight of the wooden cask was around 8% of the contained liquid, the resulting capacity of the *botte* is 0.4412 m^3 (Lane 1992, pp. 246–247). This is by far smaller than both the one of Venice (c. 0.600 m^3) and the one of Naples (0.523.5 m^3), but equivalent to the *pipa andaluza* (0.4437 m^3), also with reference to the space occupied in the hold (0.664 m^3 for both). The container, as well as the measure unit, used on board Genoese ships and called *botte*, actually was the *pipa andaluza*, adding another element to the strong maritime relations between Genoa and Spain.

3.5.1 Tonnage Formulas of Today for Genoese Renaissance Ships

On the basis of some Genoese contracts of the very last years of the sixteenth to the mid-seventeenth century, mentioning ships' dimensions and net deadweight, the existence of an empiric formula had been deduced by Luciana Gatti twenty years ago. Such a relation does not necessarily imply that a mathematical method was

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[28] By the end of the sixteenth century, for fiscal reasons this factor was officially changed to 5 *cantari/salma*, but for practical nautical use it remained unchanged.

used at the time in Genoa, even if it is not unlikely that it existed, since in Venice tonnage formula are documented since the end of the fourteenth century, as exposed in the anonymous manuscript '*Libro di navegar'*.[29] According to the formula proposed by Gatti, net deadweight (NDW) in *cantari* of Genoa (cG) resulted from the product of length, breadth, and depth of hold expressed in *palmi di canna* of 0.2477 m (pdc) divided by nine (Gatti 1999, p. 285):

$$\mathrm{NDW}_{[\mathrm{cG}]} = \mathrm{L}_{[\mathrm{pdc}]} \cdot \mathrm{B}_{[\mathrm{pdc}]} \cdot \mathrm{D}_{[\mathrm{pdc}]} \,/\, 9_{[\mathrm{pdc}^3/\mathrm{cG}]}$$

In order to compare it with Sagri's third formula, ship measures are converted into *goa* or *gobiti* (gbt) of three *palmi di canna* (pdc):

$$\mathrm{NDW}_{[\mathrm{cG}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 27_{[\mathrm{pdc}^3/\mathrm{gbt}^3]} \,/\, 9_{[\mathrm{pdc}^3/\mathrm{cG}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 3_{[\mathrm{cG}/\mathrm{gbt}^3]}$$

Transforming net deadweight into net tonnage ($\mathrm{NT}_{[\mathrm{sgS}]} = \mathrm{NDW}_{[\mathrm{cG}]} / 4_{[\mathrm{cG/sgS}]}$):

$$\mathrm{NT}_{[\mathrm{sgS}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 3_{[\mathrm{cG}/\mathrm{gbt}^3]} \,/\, 4_{[\mathrm{cG}/\mathrm{sgS}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 0.75_{[\mathrm{sgS}/\mathrm{gbt}^3]}$$

Converting into metres, the resulting block coefficient of hold is 0.485:

$$\mathrm{NT}_{[\mathrm{m}^3]} = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.75_{[\mathrm{sgS}/\mathrm{gbt}^3]} \cdot 0.2655_{[\mathrm{m}^3/\mathrm{sgS}]} \,/\, 0.7432^3_{[\mathrm{m}^3/\mathrm{gbt}^3]} = \\ = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.485$$

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} \,/\, \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 0.485$$

3.5.2 Two Genoese *navi* of the Sixteenth Century and Their Tonnage

Out of the many Genoese ships published, two *navi* of the sixteenth century are known with their dimensions and tonnage. The first one was a *nave* with a net tonnage of 2000 *salme* (531 m³), and a net deadweight of 8000 *cantari* (381 t), built in 1546 in Celle, near Genoa. Her name was '*Santa Maria'*, also known as '*Bertorota'* after her owner. Her length '*de roda in roda'* was 37 *goa* (27.53 m), her keel 25 *goa* and 2 *palmi di canna* (19.10 m), her breadth 38 *palmi* (9.42 m), her depth of hold has been estimated to half the breadth, as it was usual in Genoese *navi* of the time, 19 *palmi* (4.71 m) in this case (Borghesi and Calegari 1970, pp. 101–102). Her proportions were (0.5): 1: 2.03: 2.92 (depth: breadth: keel: length). Compared to the Ragusan *nave* described by Sagri 25 years later, her 'keel to breadth' ratio was less

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[29] 'Libro di navigar', Anonymous, end of the fourteenth century. Manuscript in Civic Library Angelo Mai (Bergamo, Italy), MA334 (Accession Number) ex Σ. VII. 29, f°18R.

than 5% larger and her 'length to breadth' ratio less than 3% smaller, with even smaller overhangs. It is possible to calculate the block coefficient of hold:

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} / \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 0.531_{[\mathrm{m}^{\mathbf{3}}]} / \left(27.53_{[\mathrm{m}]} \cdot 9.42_{[\mathrm{m}]} \cdot 4.71_{[m]}\right) = 0.435$$

definitely nearer to the block coefficients of the hold in Sagri's formula than to the one of the formula proposed by Gatti. Converting all measures in *goa* or *gobbiti* (gbt) of three *palmi di canna* (pdc), then applying Sagri's third formula, the net tonnage overestimates 6% the declared tonnage:

$$\mathrm{NT}_{[\mathrm{sgS}]} = 37_{[\mathrm{gbt}]} \cdot 12.666_{[\mathrm{gbt}]} \cdot 6.333_{[\mathrm{gbt}} \cdot 0.7125_{[\mathrm{sgS/gbt}^3]} = 2115_{[\mathrm{sgS}]}$$

It is also possible to apply the formula proposed by Gatti after converting it to obtain net tonnage expressed in *salme generali* of Sicily (sgS)

$$\mathrm{NT}_{[\mathrm{sgS}]} = 37_{[\mathrm{gbt}]} \cdot 12.666_{[\mathrm{gbt}]} \cdot 6.333_{[\mathrm{gbt}]} \cdot 0.75_{[\mathrm{sgS/gbt}^3]} = 2226_{[\mathrm{sg}S]}$$

The result overestimates 11% the declared tonnage.

The second ship was a *nave* with net tonnage of 3000 *salme 'vel* circa*'* ('around' 797 m³), and net deadweight of 12,000 *cantari* (572 t), the '*Santa Maria in Betelen',* built in 1599 in Varazze, near Genoa. Her length '*de roda in roda'* was 42 *gobbiti* (31.22 m), her keel 30 *gobbiti* (22.30 m), her breadth 39 *palmi di canna* (9.66 m), first deck height 22 *palmi* (5.45 m), second deck height 8 *palmi* (1.98 m), measured from the first deck (Gatti 1999, pp. 287–289). The height of the first deck at 5.45 m strongly suggest the presence of a level of 'naked' beams under it to strengthen hull structure, like the *baos vacíos in Spanish ships.* 'First deck to maximum breadth' ratio was 0.56 and 'second deck total[30] height to maximum breadth' ratio 0.77, while in the *nave* described by Sagri the equivalents for second and third deck were 0.50 and 0.75. The first and the second deck of the Genoese vessel corresponded, respectively, to the second and the third one of the Ragusan ship, while 'naked' beams had to be present in the former at the height where the latter had the first deck. Her proportions were 0.56: 1: 2.31: 3.23 (depth: breadth: keel: length), definitely different from those of the *nave* described by Sagri almost 30 years before: her 'depth to breadth' ratio was 12% larger, 'keel to breadth' ratio 19% larger, and 'length to breadth' ratio 8% larger. It is possible to calculate the block coefficient of the hold:

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} / \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 796.5_{[\mathrm{m}^{\mathbf{3}}]} / \left(31.22_{[\mathrm{m}]} \cdot 9.66_{[\mathrm{m}]} \cdot 5.45_{[\mathrm{m}]}\right) = 0.484$$

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[30] Measured from the keel.

the same as the one of the formula proposed by Gatti, 13% higher than Sagri's average one (0.428), and 5% higher than the third one after correction according to modern metrology (0.461). Converting all measures in *goa* or *gobbiti* (gbt) of three *palmi di canna* (pdc), and then applying Sagri's third formula, the net tonnage results:

$$\mathrm{NT}_{[\mathrm{sgS}]} = 42_{[\mathrm{gbt}]} \cdot 13_{[\mathrm{gbt}]} \cdot 7.333_{[\mathrm{gbt}]} \cdot 0.7125_{[\mathrm{sgS/gbt}^3]} = 2853_{[\mathrm{sgS}]}$$

underestimating by 5% the declared tonnage of 3000 *salme*.

Applying the formula proposed by Gatti, once converted to *salme*, net tonnage results:

$$\mathrm{NT}_{[\mathrm{sgS}]} = 42_{[\mathrm{gbt}]} \cdot 13_{[\mathrm{gbt}]} \cdot 7.333_{[\mathrm{gbt}]} \cdot 0.750_{[\mathrm{sgS/gbt}^3]} = 3003_{[\mathrm{sgS}]}$$

with a relative error of 0.1% compared to the declared tonnage.

Sagri's third formula appears to have overestimated 6% the net tonnage of the Genoese ship of the mid-sixteenth century, and underestimated 5% the one of the end of the century. On the contrary, Gatti's formula for Genoese ships, giving accurate results by the end of the sixteenth century through the first half of the following, heavily overestimated (11%) net tonnage in the mid-sixteenth century. In this case, we propose the use of a coefficient dividing by ten—instead of nine— which would have been more accurate:

$$\mathrm{NDW}_{[\mathrm{cG}]} = \mathrm{L}_{[\mathrm{pdc}]} \cdot \mathrm{B}_{[\mathrm{pcd}]} \cdot \mathrm{D}_{[\mathrm{pdc}]} / 10_{[\mathrm{pdc}^3/\mathrm{cG}]}$$

Converting *palmi di canna* into *gobiti*, according to the equivalence $1_{[\mathrm{gbt}]} = 3_{[\mathrm{pdc}]}$

$$\mathrm{NDW}_{[\mathrm{cG}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 27_{[\mathrm{pdc}^3/\mathrm{gbt}^3]} / 10_{[\mathrm{pdc}^3/\mathrm{cG}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 2.7_{[\mathrm{cG/gbt}^3]}$$

Transforming net deadweight into net tonnage, according to the formula

$$\mathrm{NT}_{[\mathrm{sgS}]} = \mathrm{NDW}_{[\mathrm{cG}]} / 4_{[\mathrm{cG/sgS}]}$$

$$\mathrm{NT}_{[\mathrm{sgS}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 2.7_{[\mathrm{cG/gbt}^3]} / 4_{[\mathrm{cG/sgS}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 0.675_{[\mathrm{sgS/gbt}^3]}$$

Converting into metres, the resulting block coefficient of hold is 0.437:

$$\mathrm{NT}_{[\mathrm{m}^3]} = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.675_{[\mathrm{sgS/gbt}^3]} \cdot 0.2655_{[\mathrm{m}^3/\mathrm{sgS}]} / 0.7432^3_{[\mathrm{m}^3/\mathrm{gbt}^3]} = \\ = \mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]} \cdot 0.437$$

$$\mathrm{bch} = \mathrm{NT}_{[\mathrm{m}^3]} / \left(\mathrm{L}_{[\mathrm{m}]} \cdot \mathrm{B}_{[\mathrm{m}]} \cdot \mathrm{D}_{[\mathrm{m}]}\right) = 0.437$$

With the latter formulas, the net deadweight and the net tonnage of the *nave Bertorota* of 1546 would be

$$\mathrm{NDW}_{[\mathrm{cG}]} = \mathrm{L}_{[\mathrm{gbt}]} \cdot \mathrm{B}_{[\mathrm{gbt}]} \cdot \mathrm{D}_{[\mathrm{gbt}]} \cdot 2.7_{[\mathrm{cG/gbt}^3]} = 8013_{[\mathrm{cG}]}$$
$$\mathrm{NT}_{[\mathrm{sgS}]} = 37_{[\mathrm{gbt}]} \cdot 12.666_{[\mathrm{gbt}]} \cdot 6.333_{[\mathrm{gbt}]} \cdot 0.675_{[\mathrm{sgS/gbt}^3]} = 2003_{[\mathrm{sgS}]}$$

with a relative error of less than 0.2% compared to the declared 8000 *cantari* and 2000 *salme* of the Genoese ship.

3.6 Comparison

The block coefficient of a ship is the ratio between the volume of the immersed part of her hull and the volume of the parallelepiped circumscribed to it. As a ratio between volumes, it is a dimensionless quantity. A similar ratio can be obtained from the net tonnage of a specific ship and her main dimensions or with a more general meaning from the transformation of net tonnage formulas. The ratio obtained from the latter is slightly different from the block coefficient of the ship, because it considers the internal volume of the hold, instead of the external volume of the hull. For this reason, in this study it has been called the block coefficient of hold. When measurements are taken up to the waterline, as in the case of Sagri's formulas, the difference consists only in the thickness of the hull. Though this slight difference, both coefficients can be taken as an index of fullness of forms of the hull: the higher the coefficient the bulkier the ship. This fullness of form can be visually represented with how slowly the main cross-section decreases in dimensions from mid-ship towards stern and bow.

The Ragusan *navi* described by Sagri in 1570–1571 had a block coefficient of hold of 0.423, 0.426, and 0.429, according to the three different formulas he proposed; in other words 0.426 ± 0.7%. Due to a certain degree of inaccuracy in measure units conversion factors used in the sixteenth century, after the correction according to modern metrology, Sagri's coefficients become more diverging, 0.400, 0.426, and 0.460, or 0.430 ± 7%, with an average 0.429. Sagri considered the ideal proportions of *navi* 0.5:1:1.94:3 (depth of hold: breadth: keel: length, all measurements but keel taken at second deck, coinciding with waterline; keel length obtained subtracting the overhangs from the length). He also stated that at his time these proportions were rarely respected in Ragusan shipyards, and that they were still the rule in Biscay, Portugal, and Genoa. The block coefficient of hold of those ships, considered by Sagri to have the same proportions, have been studied and compared, trying to understand if they also had similar fullness of forms.

In Spain net tonnage was determined in the first half of the sixteenth century with the traditional 'hoops and gauges' empirical method, and the use of mathematical methods is documented with evidence since the 60s of that century. Initially a few different formulas were in use, with different references to the vertical dimension (depth of hold), and different measure units: the *tonel castellano* or *tonelada de carga* (equivalent to eight cubic *codos castellanos*) and the *tonel macho* (equivalent to eight cubic *codos de ribera*). They were two different estimates of the volume occupied by two small casks, the *pipas andaluzas* (i.e. *de Sevilla*). By the time Sagri was writing *Il Carteggiatore*, a formula for net tonnage appeared in Spain with increasing success. In its early version, the block coefficient of the hold was slightly over 0.500. A few years later, in an attempt to be more realistic, a 5% reduction was included to take account of the taper of the hull at bow and stern and of the space occupied by pump wells. After this correction the block coefficients reduced to 0.475. In 1590 the Crown imposed the use of this formula, as well as of the *codo de ribera* and *tonel macho*, over the whole Spain.

Unluckily nothing can be said in a general way about block coefficients of hold in Portuguese ships. The empirical method using hoops and gauges to count how many casks could be stored in the hold was used throughout the whole sixteenth century to the beginning of the following. No formulas are known to have been used to determine net tonnage, but a mathematical relation existed between the later and the ship's dimensions. A formula had been proposed, but it is not possible to use it in a general way to extract the block coefficient of hold, because the vertical dimension used to determine net tonnage was not constantly proportioned to the other parts of the ship and it was situated much lower than it was done in the others examined Countries. The block coefficients of Portuguese ships can only be studied on a case by case basis.

Nothing is known about the methods to determine net tonnage used in Genoa in the sixteenth century. The only source providing some data on tonnage are notarial records of shipbuilding contracts. A Genoese *nave* built in 1546, 25 years before *Il Carteggiatore* was written, had a block coefficient of hold of 0.435, very near those of Ragusan ships, and her proportions were very similar too. The block coefficient of hold of another *nave* built in 1599 near Genoa, almost 30 years after Sagri's death, was 0.484, near the ones of Spanish ships of the time. Her proportions had moved away from those described by Sagri, as probably by that time Ragusan ships had made too.

Examining Genoese ships contracts in notarial records from the late sixteenth to mid-seventeenth centuries, a formula had been proposed in 1999. This doesn't imply that it was known or used at the time; it only explains which was the mathematical relation between ships' dimensions and net deadweight. The block coefficient of hold that can be obtained is 0.485, definitely nearer to those of Spanish ships than to the Ragusan ones. The formula fitted well the above-mentioned Genoese *nave* of 1599, but not the one of 1546, so in this chapter a modified version of the formula for net tonnage of Genoese ships in the mid-sixteenth century is proposed. A revision of measure units and conversion factors of the sixteenth century has allowed to determine that the *botte* used to transport liquids on board Genoese ships was not a local unit but a foreign one, different from those of Venice or Naples, and equivalent to the *pipa andaluza* (Table 7.5).

The block coefficients of hold obtained from tonnage formulas are compared, with particular reference to Sagri's and Barros' ones, known to have both considered measurements taken at the widest point of the ship. According to block coefficients of hold of these ships (considered to have similar proportions), Spanish ships were bulkier, with coefficients ranging from 0.475 to slightly over 0.500, while Ragusan ships were slenderer, with coefficients around 0.420–0.430. The only exception among Spanish coefficients is the one coming from the *Presidente-Visitador* formula, 0.444, definitely nearer to the Ragusan than to the Spanish ones. This formula was the only one considering the measure of the keel, as it was common in Venice since the late fourteenth century,[31] and will become in Great Britain in the late sixteenth century (Oppenheim 1896, pp. 132–133). After applying this formula to the Sagri's *nave*, the coefficient becomes 0.431, almost identical to the Ragusan ones. The place where the document containing the formula was written is unknown and for the above-mentioned reasons the latter could be of Mediterranean tradition. By the Ragusan side, some inaccuracy existed in the measure units equivalences proposed by Sagri and commonly used in the sixteenth century. After the correction according to modern metrology, the Ragusan coefficients become 0.400–0.460. The highest comes from Sagri's third formula, which used the 'western' measure units, the *gobiti*, that in his opinion were common 'out of Venice', 'through Italy and Spain', giving a possible interpretation of its nearness to the Spanish coefficients. The use of the above-mentioned block coefficients is a valuable tool to determine net tonnage (in m^3) of a sixteenth century ship, when her measures are known: just multiply Length by Breadth by Depth of hold (in metres) by one of the coefficient in Table 7.5 (ranging from 0.423 to 0.485), according to the origin of the ship, or by the average 0.454 if the origin is unknown. It is also possible to determine her net deadweight (in metric tons) by multiplying net tonnage (in m^3) by 0.72 t/m^3.

4 Conclusion

At the end of this study, *Il Carteggiatore* revealed the wealth of information it contains for the knowledge of Mediterranean naval architecture of Ragusan/Italian influence of the early modern period. The analysis of the dimensions and proportions of Sagri's *nave* allows us to reconstruct her, to compare her with what texts and

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[31] 'Libro di navigar', *op. cit.*, f°18R.

Table 7.5 Block coefficients of hold from net tonnage formulas

Author/year	Sagri first formula 1571	Sagri second formula 1571	Sagri third formula 1571	Presidente Visitador formula c.1560–1570	Vargas formula c.1565–1575	Busturia 1568, Barros 1580, *Real Cedula* 1590	proposed formula for the Genoese *nave 'Bertorota'* of 1546 (Ciacchella)	proposed formula for the Genoese *nave* '*S. Maria. in Betelen*' of 1599 (Gatti)
Original[a]	0.429	0.426	0.423	0.444	0.501	0.476	0.437	0.485
Corrected[b]	0.400		0.461					
Depth of hold / Breadth	0.5			0.5	0.5–0.53	0.5–0.53	(0.5) estimated	0.56
Breadth	1			1	1	1	1	1
Keel / Breadth	1.94			2.13	2	…	2.03	2.31
Length@ WL / Breadth	3			3.20–3.27	3–3.07	…	2.92	3.23

[a] according to the sixteenth century equivalences

[b] according to the modern metrology equivalences

archaeology tell us about the Mediterranean merchant ships of the time, and finally, to compare her with those built in the Iberian world.

Although the proportions of Sagri's *nave* appear to be widely used in European shipbuilding at the time, two out of the three net tonnage formulas he recommended for were unknown. They have been studied with an innovative method through the use of block coefficients. This allowed to go beyond what Length/Breadth/Depth proportions express, by showing that Italian/Ragusan ships were in general less bulky than those of Iberian shipbuilding with similar ratios and main dimensions.

Finally, it should be pointed out that this study does not deal with other important aspects that the manuscript highlights, in particular that of the ship's masting and sails, to which Sagri devotes a large part of his text (Chaps. 8, 9, 10, and 11 i.e. 23 folios), or that of anchors (Chap. 12). For a more in-depth knowledge of the ragusan *nave*, it will be worthwhile in the future to continue the work undertaken by a study of these themes.

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