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Practical Knowledge in the Viking Age: the use of mental templates in clinker shipbuilding

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It has long been recognized that ships built according to the Nordic clinker tradition during the Viking Age were conceived and constructed simultaneously by eye, in a shell-first manner, and using rules-of-thumb to control both the longitudinal and transversal shape of the hull. While a lot of attention has been paid to the conceptual definition of the keel and stems, far less research has explored how such rules would have worked while planking the hull. Two cargo-ships, Skuldelev 3 and Skuldelev 1, are used to argue for pre-design and the use of mental templates. This highlights a cognitive dimension of practical knowledge, in particular how it was accumulated, stored and transmitted.

Key words: Shipbuilding, rules-of-thumb, knowledge production, building by eye, Skuldelev.

Since Hasslöf (1958) described the distinctive concepts of shell- and skeleton-construction, perceiving boats essentially as a 'watertight shell' or 'waterproofed frame', archaeologists have used these notions to classify, interpret and explain the construction of the great variety of hull shapes found in the archaeological record. Even though some have been critical of this dichotomy and found it too restrictive (Basch, 1972: 17; Hocker, 1991: 12), it remains very influential in current interpretations of archaeological ship remains (Crumlin-Pedersen, 1997; Crumlin-Pedersen and Olsen, 2002). Notions of pre-design and rules-of-thumb are frequently cited in discussions of the construction of clinker-built boats (McGrail, 1987: 98–103, 2003; Crumlin-Pedersen and Olsen, 2002: 235–8; Adams, 2003: 51–2; Crumlin-Pedersen, 2004: 50–53). However, these insights are hampered by some of the implications of the term 'shell-construction', in particular the primary (but not exclusive) focus on longitudinal aspects of hull design. This paper aims to redress this imbalance.

Therefore, without ignoring that a ship is conceived and built as a three-dimensional shape, in this study we choose to focus on the transverse conceptual definition of clinker-built hulls in the Viking Age. Using published ethnographic material and the available primary archaeological data from two cargo vessels, Skuldelev 3 and Skuldelev 1, both dated between *c.* AD 1030 and 1050, and originating respectively from western Denmark and western Norway, an argument is made for pre-design and the use of mental templates. These mental templates, as defined by the authors, contain a series of rules-of-thumb that apply both to the longitudinal (backbone) and transversal plane (hull sections), with no distinction between the two. It is thus suggested that Viking Age ships may have been designed and built with sectional shapes as part of the process. The concept of building 'by eye' is examined, as are the roles of mental templates in accumulating, storing and transmitting practical knowledge.

This paper is intended as a contribution to three aspects of Viking Age shipbuilding: first, by continuing the debate about conceptual approaches to shipbuilding and the use and application of rules-of-thumb, specifically in planking the hull; second, by attempting to further clarify the combined use of 'eye' and 'rule' in clinker shipbuilding; and third, by exploring practical knowledge through a cognitive lens and focussing on how knowledge is preserved and disseminated.

Interpreting Nordic clinker-construction

Ships built according to the Nordic clinker tradition during the Viking Age were conceived and constructed simultaneously by eye, in a shell-first manner, and using rules of thumb to control the three-dimensional shape. The boatbuilder would thus shape the planks for the hull individually and fit these together without the aid of frames or moulds. Given the current widespread acceptance of this method of construction, it is easy to forget that in 1950 the Oseberg ship was essentially published as a ship built on moulds based on the 'skeleton-first' concept (Brøgger and Shetelig, 1950).

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Norwegian archaeologists Anton Wilhem Brøgger and Haakon Shetelig engaged naval architect Fredrik Johannessen to restore the ship after its excavation in 1904 and subsequent conservation. Based on his expertise, they concluded Viking Age ships had probably been built using a set of temporary moulds that determined the cross-sections of the hull at various points in the ship (Brøgger and Shetelig, 1950: 109).

It was only in the 1960s when a group of Scandinavian researchers, including Olof Hasslöf, Arne Emil Christensen and Ole Crumlin-Pedersen, set out to find a link between the archaeological finds and the living traditions of clinker-boatbuilders that the notion of clinker-built ships constructed without the use of physical or visual aids was put forward. Within the Danish, Swedish, and east Norwegian regions they found a number of boatyards in which local clinker-construction was based on the use of temporary moulds as a guide to shape the plank shell of a boat. Christensen set this aside as a relatively recent influence introduced from carvel construction (1972: 252). In western Norway they found what they were looking for. Crumlin-Pedersen (2004: 40–1) wrote: 'In this region the boat builder, as a sculptor, shaped the planks for the hull individually and fitted these without any support or guidance from moulds or frames. He would rely on a trained eye and simple control levels to give the plank shell of the boat the exact shape he wanted'. Similar ideas can be found in the work of Christensen. For example, in his influential chapter in the English publication of the results of their ethnographic research (Christensen, 1972), he argues that clinker-boatbuilders have 'tools to aid the eye' in the construction process. These observations have been widely accepted in Viking Age ship interpretation; for example Crumlin-Pedersen wrote (2009: 153): 'The shape [of the hull] was controlled by the trained eye to achieve the desired sculptural hull form, possibly using a few control measurements to compare with boats built previously.'

The current use of the term 'building by eye' implies that clinker-builders base most of their design decisions on a visual appreciation of the shape as it is being built. The tools appear to perform a secondary role. Here we argue the opposite; clinker-builders base most of the design on inherited rules-of-thumb and use the eye as a design-aid and not as the principal design-tool. It is thus necessary to carefully define what is meant by 'building by eye' in the archaeological literature.

Crumlin-Pedersen describes the boatbuilder as a 'sculptor', relying on his 'trained eye' to give the boat its hull shape. Elsewhere, he compares the construction of a boat without plans to the work of an artist (for example Crumlin-Pedersen, 2009: 147), something which Christensen has never done. The term 'artist' in an archaeological context, laden as it is with modern and western meanings, should be used with care (Gell, 1992). However, one should read these statements in the context of a field influenced by marine engineers and shipwrights, to which Crumlin-Pedersen perhaps wanted to provide some counterweight. He may have wanted to emphasize the dangers of looking at Viking Age ships through the eyes of a modern naval architect. That he saw Viking Age boatbuilders as craftsmen rather than artists in the strict sense is perhaps seen in his acceptance of design aids, rules-of-thumb and some form of standardization in Viking Age shipbuilding.

Crumlin-Pedersen himself discovered a rule-of-thumb based on radii of circles related to the length of the keel, underpinning the shape of the stems of Skuldelev 3 (Fig. 1) (Crumlin-Pedersen and Olsen, 2002: 235–8). Because these stems were prefabricated, he concludes:

> '[. . .] that the boatbuilding master had fixed the whole concept of the ship, namely the total height of the sides as well as the run of the lines for each plank near the ends before the keel had even been laid. How could this have been possible? Only if the Viking Age shipbuilding master, the so-called stem-smith, had a set of rules-of-thumb to work from. Of course there is a reason to believe that the experience gained by his predecessors had been laid down in such rules.' (1986: 143)

Evidently, Crumlin-Pedersen was a proponent of the use of rules-of-thumb in the construction of Nordic clinker-built ships and even argued for a limited form of standardization to facilitate work and ensure a degree of uniformity (Crumlin-Pedersen and Olsen, 2002: 238; Crumlin-Pedersen, 2004: 50–1). However, it is peculiar that, although he suggested the use of rules-of-thumb in both the longitudinal and transversal planes, he did not attempt to formulate how such rules would work in the transversal plane. Perhaps, this is because he knew from studying the Skuldelev remains that the plank breadth in Viking ships could vary considerably on each side, thus compromising symmetry, which casts doubt on the use of such rules. This issue will be explored further when discussing the Skuldelev 1 and 3 ships.

Seán McGrail (1987: 252) makes the point that some aid to achieve the final form is likely. He argues that, since there have been no design aids found before the Post Medieval period, the design might have been expressed in rules-of-thumb. However, he reasons that any such rules would have to define strake shapes. To date, no such method has been described. The final three-dimensional form would thus be achieved 'by eye' as individual planks were fitted. However, he also states that for very large clinker-built ships, such procedures would be impracticable. In a more recent a chapter on Viking Age shipbuilding methods, aimed at a wider audience, McGrail (2013: 50) clarifies: '. . . the master builder achieved the hull shape he required by varying the strake breadths and the angles at which each strake was fastened to the one below'.

Godal (1990) identified several rules-of-thumb in western Norwegian boats and Viking Age ships.

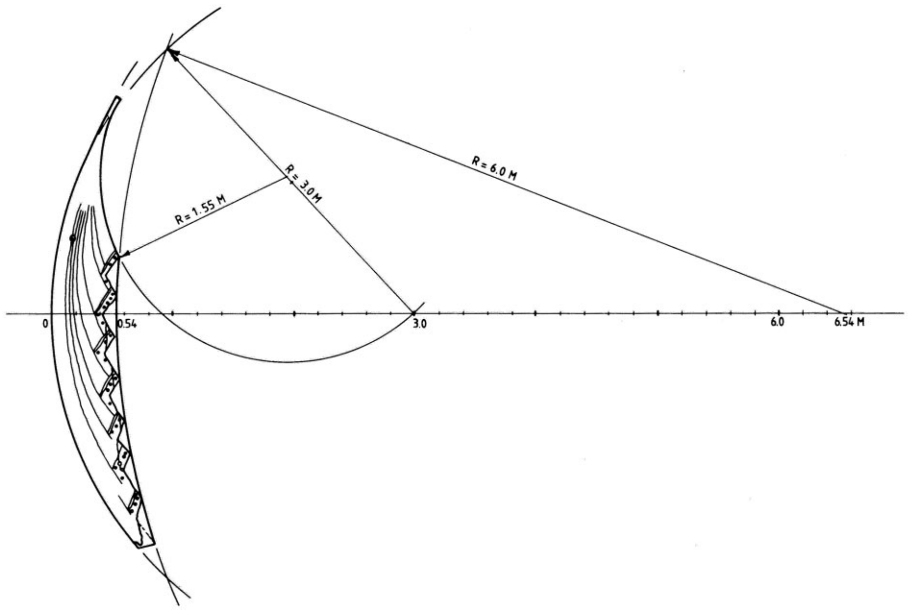

Figure 1. Geometrical stem design. (Crumlin-Pedersen, 1986: 143, fig. 5, with permission © Viking Ship Museum in Roskilde, Denmark)

He illustrated how the radii of the stems are proportionally related to keel-length, similar to Crumlin-Pedersen's findings for Skuldelev 3. However, he also extended his analysis to the rest of the hull shape and discovered that the beam at certain positions along the length of the hull is proportionally related to keel-length, in effect devising a rule that defines 'control points' in the transversal plane. Similarly to Crumlin-Pedersen, Eldjarn and Godal (1988) believe that detailed knowledge of how to control hull shape was transmitted as basic rules incorporated in a code known only to a few. These rules were used to repeat a design, scale it up, or to adapt it for different functions or environments.

While rules-of-thumb have been widely accepted, most researchers have concentrated on their use for defining the longitudinal structure combined with the primary role of the 'eye' to define hull shape.

Building 'by eye', a problematic concept

In the context of this paper, building 'by eye' refers to a method of building ships in which the shipwright's 'eye' is the principal design and construction tool. Although designing and building smaller craft 'by eye' might have been possible for skilled boatbuilders, questions arise over the construction of larger Nordic vessels. One thought that comes to mind is that of obtaining the right perspective to visualize a large ship in its entirety. Being able to judge its shape 'by eye', preferably from a variety of vantage points, might not be possible if the ship is being built in an enclosed space, encumbered by the scaffolding and support structures needed to build a large ship. Besides these exclusively practical aspects that render building a large ship 'by eye' an impractical undertaking, there are some higher-level considerations that must be evaluated.

First, building 'by eye' does not explain how the tacit knowledge of a certain hull shape was conceived, attained, stored or transmitted. The general assumption that the shipwright relied on his memory and experience attained by previous builds is not satisfactory: it fails to explain how an apprentice receives the shapes stored in his master's memory. Apprentices learn by copying and repeating the actions and movements of their masters, and in the process memorize the basic design practices involved in building a ship. This is the essence of the apprenticeship; learning by doing. Perhaps the concept of mental templates can help us understand this process in greater depth. Furthermore, as Adams (2003: 51–2) has argued, it is worth pondering the enormous investment in resources necessary to construct large ships such as Skuldelev 2 (Crumlin-Pedersen and Olsen, 2002: 141–94) or Hedeby 3 (Crumlin-Pedersen, 1997: 99–104). Even though such considerations inherently apply a modern concept of administrative management to a society that managed resources in a very different way, it is still worth considering if these resources would have been entrusted entirely to the shipwright's optical judgement.

Some practitioners of the shipbuilding trade will have been better than others and a king or chieftain would probably not have entrusted valuable resources on this scale to somebody without a proven record of success in building seaworthy ships. We must bear in mind that the construction of a ship was to a certain extent a throw of the dice; there was no way to know how a ship would perform before it went into the water. Having a method of preserving the shape of good ships so that it could be repeated or improved would certainly have been an advantage and would have increased the chances of success. Mental templates might have been what ensured a relationship of trust between the customer and the shipwright.

Mental templates in clinker-construction

The term 'mental template' is not new and was used by Crumlin-Pedersen (2004: 51). The authors define mental templates as a series of rules-of-thumb wherein a boatbuilder stores and transfers his knowledge of how to obtain the form and proportions of a hull shape. These mental templates contain rules for both the longitudinal and transverse plane. A 'rule-of-thumb' is a rough guide or principle, based on practice rather than theory, which has a broad application and is not intended to be strictly accurate or reliable in every situation.

The following sections will argue that Viking Age clinker-builders not only had means to control the shape of the stems of their hulls, but could also envision the hull as a series of transverse sections. In doing this, we explore how rules-of-thumb could have been applied in planking a ship and the combined use of 'rule' and 'eye' in Viking Age shipbuilding.

Had there been physical remains of these transversal sections, they would have resembled the moulds used in more modern clinker-building. However, no moulds have been found in the archaeological record, not even at known shipyard sites such as Fribrødre (Skamby-Madsen and Klassen, 2010). Despite some traces on excavated shipwrecks that could be interpreted as markings left by moulds, it is still hard to argue for their existence. Therefore the argument is for virtual moulds, based on inherited rules-of-thumb as part of a mental template, which guided the shape of the transverse sections of the hull.

Ethnographic evidence

Ethnographic research of traditional boatbuilders in Scandinavia showed that modern-day clinker-builders considered moulds to be a recent addition to their set of tools (Christensen, 1972: 256). However, the practicalities of planking a boat in clinker-building allows for the construction of a hull without a physical mould, while the shape is controlled by a series of bevels and plank widths that together form a non-physical mould that performs in much the same manner.

The tools and procedures used to define hull shape in a traditional clinker-built boat in western Norway have been described in the literature (Christensen, 1972; Klepp, 1983; Eldjarn and Godal, 1988) and have since been the main basis for the interpretation of the Viking Age shipwrecks found in the archaeological record. In this paper, the ethnographic evidence will be used to show that the transverse cross-sections play an important role in shaping the hull. But first, a discussion on the conception of hull shape by shell-builders building in the clinker-technique is necessary, as well as a general explanation of the practicalities of clinker-construction, as this will help to understand the use of mental templates proposed.

Building with pre-formed planks?

In a wooden boat or ship, each plank is shaped differently to its adjacent planks. Furthermore, changes to the intended curvature of the hull surface will result in planks of a different shape. The archaeological literature on ship construction methods does not include any specific suggestions as to how planking shapes could be predefined to obtain a particular hull. However, the actual building procedures followed by traditional clinker-builders are proof that other more practical and simple methods were available.

In a traditionally built clinker boat, the lower edge of the plank is largely defined by the upper edge of the plank against which it fits (Fig. 2). Thus, a clinker-builder does not need a method of pre-defining the shape of the plank in order to build a hull. The technique requires no accurate measurements or drawings of any kind. The new plank is bent against the previous strake, with the correct twist to obtain the flair required by the boatbuilder, and the shape of the matching edge is obtained.

Building 'by eye'

The procedure followed to build a clinker boat in the traditional manner requires no moulds to derive the transverse shape of the hull (Figs 3 and 4), but neither is it built by eye. The shape of the hull is obtained by an inherited rule-of-thumb which defines the angle of each plank and its width at key control points. The 'eye' is still of importance in judging these angles and breadths and is essential in choosing which line to fair between the control points defined by the rule. The procedure followed to shape the hull is conceptually simple: the backbone is erected (keel and stems) and the garboard is fitted against it. It must be offered in place, measured, trimmed and offered again several times until a good fit is obtained. The plank offered in place is not an unworked plank, but already has been approximately shaped to allow for the desired amount of twist. Meanwhile, the deadrise angle of the garboard is checked at several key control points so that it runs with the correct twist, which is maintained by a series of props taken to a strong point overhead (Fig. 3a). Once the fit with the keel and stems is acceptable, the garboard is fixed permanently to them. Similarly to the deadrise angle, the breadth of the plank is subsequently marked at some pre-established control points (Fig. 3b). These marks are joined, freehand or with a batten, and the plank is cut to the line (Fig. 3c) (Christensen, 1995: 14). The next strake is fitted against

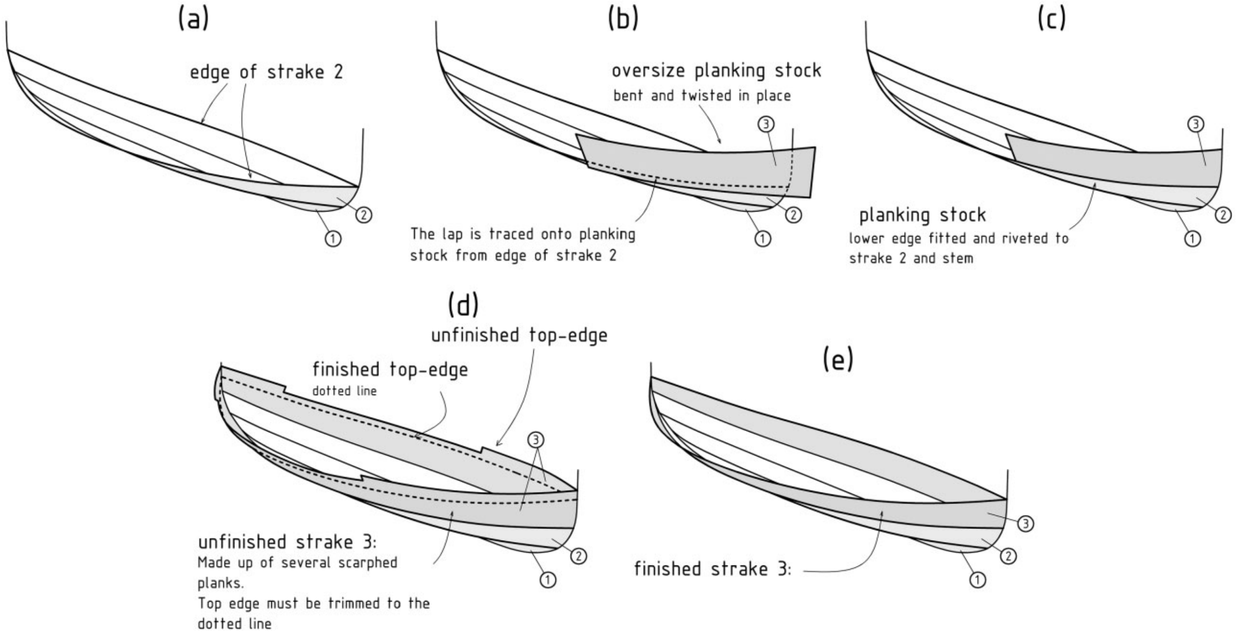

Figure 2. Process of deriving the shape of a strake in traditional clinker-building: (a) the first two strakes are set in place; (b) an oversize plank is offered in place and bent and twisted according to the shipwrights design; the overlap and stem are marked on the plank; (c) after cutting to the marks traced in (b) the plank is fixed permanently to strake 2 and the stem; (d) the strake is finished by scarfing other planks following steps (b) and (c); the finished strake edge is marked; (e) the strake is trimmed to the mark. (Drawn by authors)

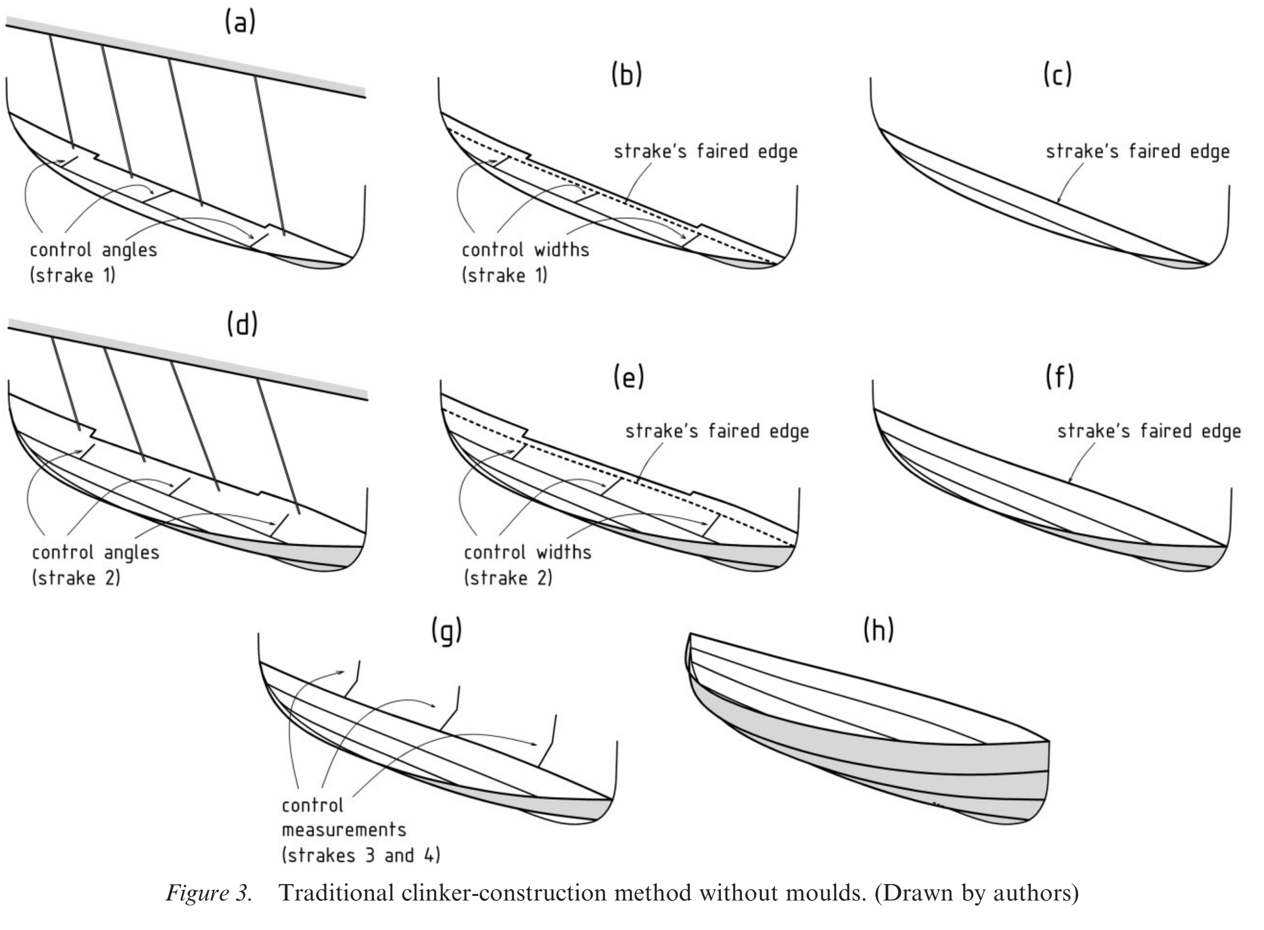

Figure 3. Traditional clinker-construction method without moulds. (Drawn by authors)

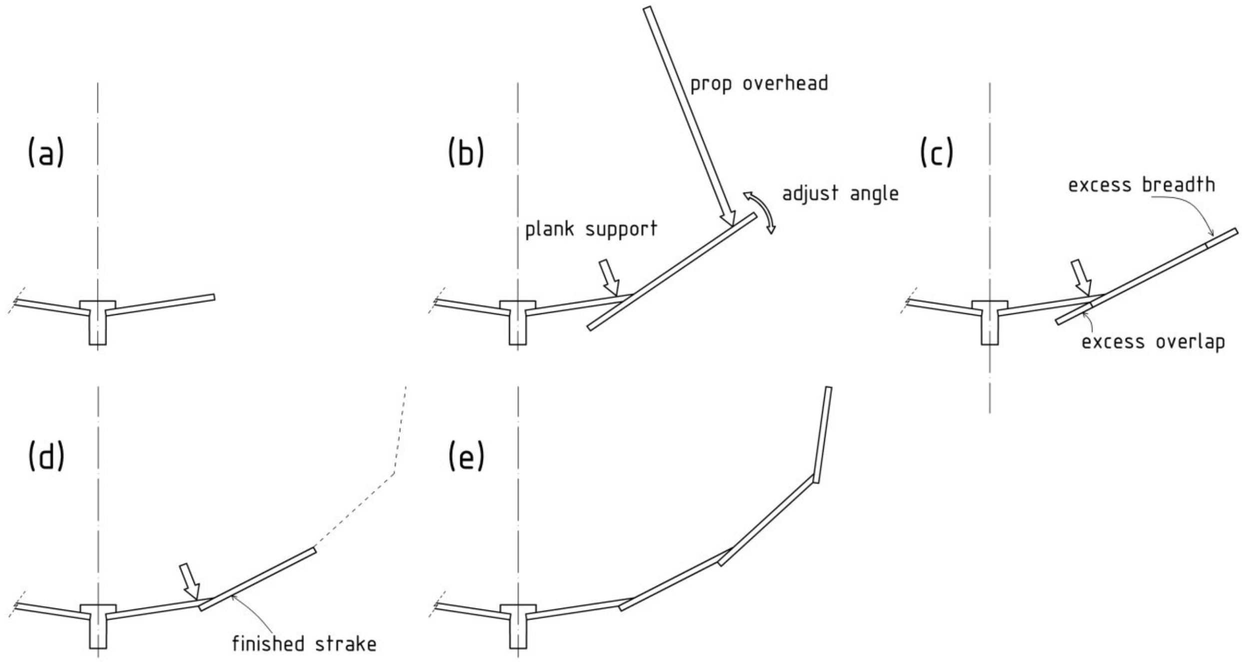

Figure 4. Traditional clinker-construction method without moulds viewed in section. (Drawn by authors)

the garboard, following the procedure in Figure 2. Again, the control of the angle at key points is ensured by props taken to a strong point overhead (Fig. 3d). The strake is fixed permanently to the garboard, and then its breadth at the control points is marked, a line faired through them, and the strake is trimmed to it (Fig. 3e, f). This procedure is followed for the rest of the strakes. After the bottom strakes are attached, the floor timbers are inserted.

The shape of each strake is obtained from the previous strake, and the boatbuilder uses the angle and width of each strake at key control points to shape the hull (Christensen, 1972: 241). Thus it can be said that the method of shaping the hull is based on the design of the keel and stems (Crumlin-Pedersen, 1986; Indruszewski, 2004: 181), but also on the transverse sections defined by the breadth of each plank and its angle, at key positions along the length of the hull. If one considers the angles and plank breadths of each strake at a given control position along the hull (for example the midship section) (Fig. 4), it can be seen that together they define the shape of the transverse section. This shape could be assimilated to the concept of a mould. In the case being described, the mould would not be a physical object, but a virtual mould, part of a mental template that the boatbuilder would use to define the shape of the hull. Another way of looking at the use of bevels and strake widths is that they define the longitudinal shape of each plank: the construction sequence and absence of physical moulds means that each plank is shaped over its length in turn.

Even though the procedure outlined above does not necessarily leave physical traces, it is interesting to note that on certain strakes of the Roskilde 3 Ship, dating from around AD 1060, markings were found on the strakes. Sometimes these corresponded to the locations where frames were inserted, but in certain places this is not the case (Bill, 2006: 10). Could these be the control points proposed? The keel of Hedeby 1, dating from *c.* AD 985, has small hollows bored in the top which generally correspond to the positions of the floor timbers. However, at certain places these are out of position and may have served an alternative purpose (Crumlin-Pedersen, 1997: 87). There is also direct evidence for the procedure from the clinker-built ship of medieval date (mid 15th century) found in Newport, Wales (Nayling and Jones, 2014). On this vessel, rows of nail holes along the top inboard edge of the planks' lower land were found. These are interpreted as temporary supports for the planking during scribing the shape (pers. comm. Pat Tanner, 2014).

The 'eye' of the boatbuilder plays an important part in judging and adjusting the angle, in ensuring that the free edge of the plank is trimmed following a fair curve and, perhaps, even in judging the width of the strakes. Most importantly, the eye chooses which fair line to take through the control points defined by the rule. However, it is the underlying rule-of-thumb that is responsible for creating the shape, and not the eye. This was expressed very clearly by Eric McKee when he wrote about building a simple hard chine boat:

'. . . what Mr Baker then did to build the boat looked as if he were working by eye, especially as he was constantly looking to see that his curves ran fair and flair angles were regular. However it was the remembered rule-of-thumb which told him the size to make the deck and the internal shape of a turf boat 17ft overall.' (McKee, 1983: 109)

The eye is thus important as a fairing-tool and will, to a certain extent, make design decisions within the limits that the rule allows; however the basic design comes from the inherited mental template. Similarly, when a modern-day boatbuilder lofts the plan of a boat or ship following the exact dimensions given in the table of offsets defined by the naval architect, the eye plays an important role in ensuring that the lines produced by the batten bent to the offsets are fair. Both the 'mental template' and 'the eye' should thus be regarded as inseparable parts of the construction process of a clinker-built ship where both work together and one does not take priority over the other.

Control tools to define transverse shapes

Ethnographic research has recorded a number of tools and procedures that can shed light on how a transverse section could have been controlled by Viking Age boatbuilders. Christensen (1972: 241) acknowledged that the shape of a hull could be fixed as a series of plank widths and angles; however, he did not observe that this might constitute a transversal conception of the shape of the hull, but rather a means of describing the shape of each individual strake. On the other hand, McKee (1983: 113) realized that by controlling plank widths and angles in a clinker boat, the boatbuilder was defining the shape of the transverse section of the hull. He wrote that the shape of the transverse sections of a clinker hull built without moulds could easily be converted into simple rules-of-thumb that took these two variables into consideration (McKee, 1983: 112). He did not consider these widths and angles as defining the shape of each individual strake, but that the ensemble of angles and breadths defined the transverse sections of the hull.

McKee (1983) recorded cases in which clinker boats were shaped by controlling strake widths and angles, and witnessed how experienced boatbuilders could set the angle 'by memory', having done it so often, while less-experienced apprentices needed a hand-held bevel-mould (McKee, 1983: 110). He realized that even though experienced builders, by way of repetition, could judge this angle reliably enough without a physical mould, the virtual mould, and thus the rule held in their minds, guided their actions.

To support the idea of a virtual mould, as a means of guaranteeing adequate transverse sectional shapes in clinker-building, as suggested by both McKee (1983) and the present authors, the tools observed in ethnographic research on the western coast of Norway will be described briefly. These tools are believed to have been in use for centuries, and their use in Viking times is highly likely, although it has not been proven (Christensen, 1972: 252).

Boat-levels

Christensen (1972) identifies two types of boat-levels being used at the time of their research: a building-level and a control-level. They are both a simple board with a small plumb-bob hanging from it (Fig. 5). They work by measuring the angle defined by the strake and the plumb-bob. According to Christensen (1972: 242) the building-level gives important information about the shape of the hull. The angle of each strake at key points along the length of the hull is marked on it. With these angles and the widths of the planks this tool is sufficient to describe the transverse sections of the hull at those key points. A control-level is a similar device but with a simpler use. It is used to transfer the angle of a pre-installed strake to its matching pair on the opposite side of the boat so that symmetry of the hull is maintained (Christensen, 1972: 242).

Measuring-stick or boat-ell

A boat-ell is a stick on which the builder records a series of marks that describe important measurements of the ship. These measurements might be distances from the edge of each strake to a taut string stretched between the stems of the hull (Christensen, 1972: 239). Similarly to the control levels, the distances marked on

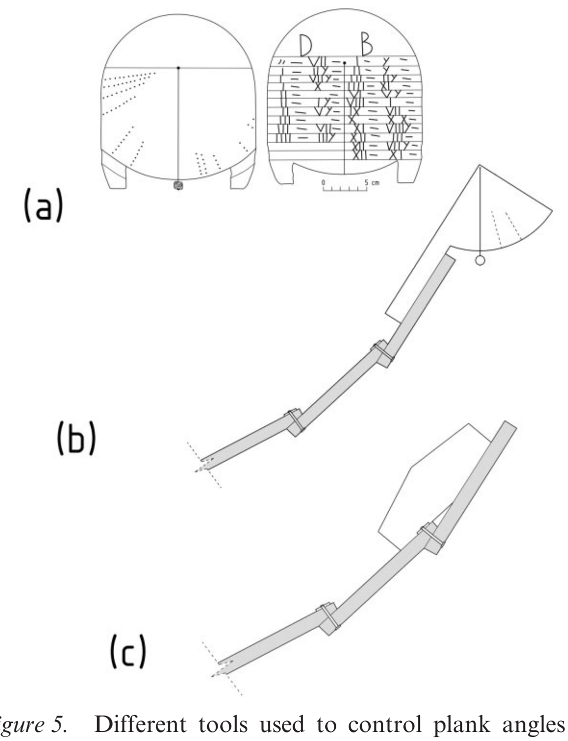

Figure 5. Different tools used to control plank angles in traditional clinker-construction: (a) Boat level with angles for a 12 planks boat; (b) and (c) control levels and their use. (Drawn by authors, (a) level from Hvaler, Østfold in the Norwegian Maritime Museum (N.S.M. 2823.), drawing based on Christensen 1972: 240–1, fig. 2a and fig. 2b)

the boat-ell, together with the breadth of the planks, define the angle of the plank. These measurements can be at several control points along the length of the hull. If all the measurements at one control point are taken together, they can be seen to define the transverse section of the hull at that point.

Bevel-board
Boat-levels and boat-ells describe full sections of the hull. The bevel-board, on the other hand, is used to control the angle between two adjacent strakes (Christensen, 1995: 18) (Fig. 5). As it will be seen in the analysis of the two Viking Age hulls, the cross-sectional shape of the hull can be defined at a specific point with one or two bevel-boards only.

Story-stick
A story-stick or story-pole is a simple wooden device, for example a board, used in carpentry and furniture-making to record different dimensions for the construction of a wooden object, such as a piece of furniture or a staircase. Christensen (1972: 253, fig. 10) describes such objects in use in Norwegian clinker-building, and calls them 'recipes' (Fig. 6). The story-stick, or 'recipe', described by Christensen contains information of plank widths, bevel angles and so on at specific points on the hull that allow a boat to be built from them. It contains information in both the transverse and longitudinal planes.

The conceptual definition of a section

In this attempt to study the conceptual definition of a transverse section, it is hypothesized that Viking Age boatbuilders would have rules-of-thumb providing information on the transverse plane such as plank angles and breadths at certain key points along the length of the boat. Sectional shapes would thus have been an integral part of the design and building process. Following McKee, these angles and breadths define transverse sections in just the same manner as a physical mould would. It can be said that they are virtual moulds and part of a mental template. The more modern mould can be seen as a physical manifestation of those angles and breadths. One would be forgiven for thinking that once the physical mould was adopted, mental templates would be abandoned; however, that is not the case. Christensen (1972: 255, fig. 12), studied a clinker boat being built on three moulds (Fig. 7), but the builder used the moulds as a rough guide only. The boat being built is wider than the moulds, but instead of making new moulds, or indeed of building 'by eye', the builder built a boat of a new shape that is somewhat related to the narrower moulds. They serve as reference for the mental template that the boatbuilder used to shape the boat. This example perfectly illustrates the interplay between mental templates and the 'eye' where both are necessary to construct the required hull shape. Furthermore, it shows how mental templates provide a basis for further improvement of the design.

The rule-of-thumb could be translated into physical form as a story-stick on which critical measurements such as plank widths and bevel angles were recorded

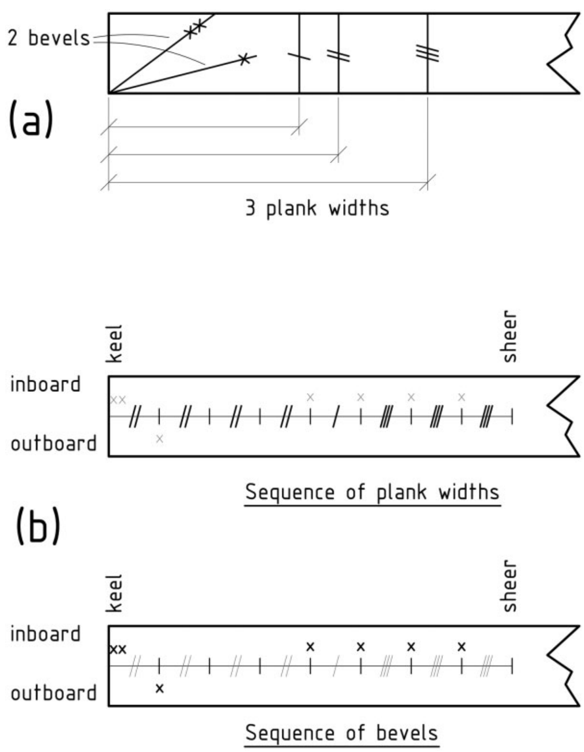

Figure 6. Story pole or 'recipe' with information needed to build the master section of Skuldelev 3: (a) plank widths and bevel angles; (b) and (c) assembly sequence, indicating the order in which the different plank widths are used, and the side to which the bevels are applied. (Drawn by authors, after Christensen 1972: 253, fig. 10)

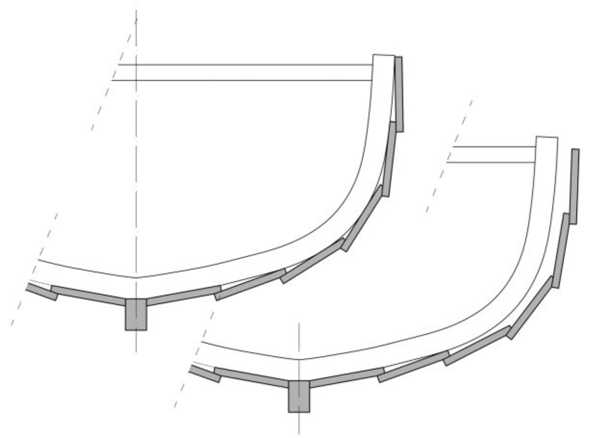

Figure 7. Moulds used as a visual aid only. Boatbuilders will sometimes build a wider boat than the moulds are designed for. (Drawn by authors, see Christensen 1972: 255, fig. 12)

(Fig. 6). It could also be translated into a boat-level on which only angles were recorded. In a simpler form it could be converted into a verbal rule-of-thumb, less precise than the two aforementioned methods, but an effective memory aid as well (McKee, 1983: 120). The aim of these rules-of-thumb, and the mental templates produced by them, is not to lead the construction of the hull in a rigid manner. The builder follows them, but has the liberty to effect small adjustments as necessary. It is common for traditional clinker-builders to sometimes divert from the measurements given on their tables and bevel-boards in order to suit the variable dimensions of the materials (Christensen, 1972: 243), or the requirements of the customer.

What is described above is a 'design method' which can be put into practice in a number of different 'construction methods'. These 'construction methods' are no more than translations of the rules-of-thumb into working procedures (for example Fig. 3). An alternative construction method would be to take predefined measurements between a string strung between the stems and the top edges of certain strakes, or to take measurements from the keel to the top edges of certain strakes. These different methods accomplish the same result: they control the design principles; the angle and width of the plank, and therefore the transverse shape of the hull. However, there is no reason to suggest Viking Age boatbuilders would have made the same distinctions between 'design' and 'construction', in effect 'theory' and 'practice', as we do today.

The archaeological evidence

The previous section has argued for the existence of rules-of-thumb stored in mental templates that helped the boatbuilder conceive the three-dimensional shape of the hull, based on the definition of key dimensions and proportions in both the longitudinal and transversal planes. The application of rules-of-thumb in the longitudinal plane has been discussed at length by Crumlin-Pedersen (Crumlin-Pedersen and Olsen, 2002: 235–8). Therefore, the analysis of the following two hulls from the Viking Age will concentrate on the application of rules-of-thumb in planking the hull.

The aim of the analysis of the hulls is not to find the exact rule that guided the builders in the construction of each of the ships; it is expected that the builders would use the rule as a guide and not as a strict reference. The purpose of the analysis is to try to establish a general rule for each of the ships that results in sectional shapes that approximate the original accurately enough to be able to state that this rule, or another similar rule, could have been used to derive the shape of the hull. The following analysis has identified rules-of-thumb for the shape of the master frame of each of the hulls. In theory, a virtual mould of just the master frame would suffice to produce a hull shape. However, it is most probable that rules for other sections would also exist.

Skuldelev 3, a small cargo carrier

The first hull analysed is that of the Skuldelev 3 wreck, a small cargo carrier with a reconstructed length of 14 m and beam of 3.28 m. It was excavated between 1957 and 1962 as part of the blockage formed of five ships in the Roskilde Fjord in Denmark. Dendrochronology produced a felling date of the trees used to build the ship of *c.*AD 1030–1050, and traced the origin of the wood to western Denmark (Crumlin-Pedersen and Olsen, 2002: 240–1).

The analysis was conducted on the primary data available for Skuldelev 3. The original full-scale drawings of the planks, scaled down to 1/10, were pieced back together at four separate sections (Table 1). A light board was used to join the rivet holes of adjoining strakes and, by doing this, the inboard width of the strakes were measured. This excludes the overlap which can vary considerably along a strake and, most importantly, following the method of shaping the planks described in Figures 2 and 3, the boatbuilder would decide the width of the new strake by determining its breadth on the inboard (pers. comm. Pat Tanner, 2014). When this is taken into consideration, it becomes apparent that the disparity in the whole widths of planks from opposing sides of the hull is not as important as might be thought.

Table 1. *Measurements of the internal width visible between each land taken from the full-scale drawings of the strakes of Skuldelev 3*

Strake	4A	3A	0	3F	Zone
Port Sections					
			Width (mm)		
8	255	310	330	300	
7	265	300	370	305	Side
6	270	280	300	300	
5	135	160	200	160	Bilge
4	170	205	230	190	
3	150	165	230	170	Bottom
2	215	235	240	210	
1	210	230	250	210	
Starboard sections					
1	200	200	215	170	
2	Damaged	220	210	205	Bottom
3	Damaged	180	250	190	
4	—	160	225	170	
5	—	145	205	140	Bilge
6	—	275	315	310	
7	—	Damaged	350	300	Side
8	—	—	291	310	

The bevels were analysed on the reconstructed lines plan. Even though the bevels in the original ship would probably not have been as symmetrical as they are on this plan, the general shape of the vessel has been reconstructed as accurately as possible to the archaeological material (Crumlin-Pedersen and Olsen, 2002: 226), and is sufficient for this analysis. However, it should be stressed that the reconstructed lines plan cannot be used for the analysis of strake width. Because the cross-sections were drawn by fitting the strakes into them, thus manipulating their shape, they are used here for illustrative purposes only and were not used in the analysis.

Rule-of-thumb for Skuldelev 3

At first glance, the variability in the measurements of the strake widths (Table 1) might appear to argue against the use of any sort of design rule. However, as Hocker (2013: 72–84) has recently pointed out, in our search for the creative spark behind the conceptualization of different shipbuilding traditions, it is easy to forget the messy reality of building wooden ships. No ship corresponds exactly to the ideal conceived in the mind of the shipwright, and many do not even come close. Most ships are certainly symmetrical in concept, but the process of construction will inevitably introduce asymmetry and irregularities to a greater or lesser degree (Hocker, 2013: 74). In the case of Skuldelev 3, when taking into account that a fair number of strake widths could have been judged using a simple tool, such as hand measurements (Godal, 1990: 56–7) or even 'by eye', these discrepancies are to be expected. Furthermore, it is likely shipwrights would not have discarded wood easily, and would work with the timber they had available. Some level of symmetry would have been assured through the interplay between slightly varying angles and strakes widths. A boatbuilder would thus play within the limits defined by the rules.

From this perspective, it is clear from the plank widths and the reconstructed bevels (Fig. 8) that the boatbuilder thought of his ship in several zones: bottom, bilge and sides. It is not inconceivable that the 'control points' identified by Godal (1990) would be located at the transition of these zones. However, the boatbuilder needed a clear idea of the average angles and widths the bevels and planks should have in each of these zones.

The following simple rules-of-thumb can define the master section of the Skuldelev 3 ship with a high degree of approximation to the reconstructed shape. The ship is divided in three zones—bottom, bilges and sides—made of planks of similar width. It should be clarified that to produce Figure 8, the interior widths of the planks of each of the three zones have been averaged (Table 1) and a constant landing of 50 mm was added. This is in keeping with the idea that the boatbuilder would have a rule to guide him but with leeway to suit the variable dimensions of the materials

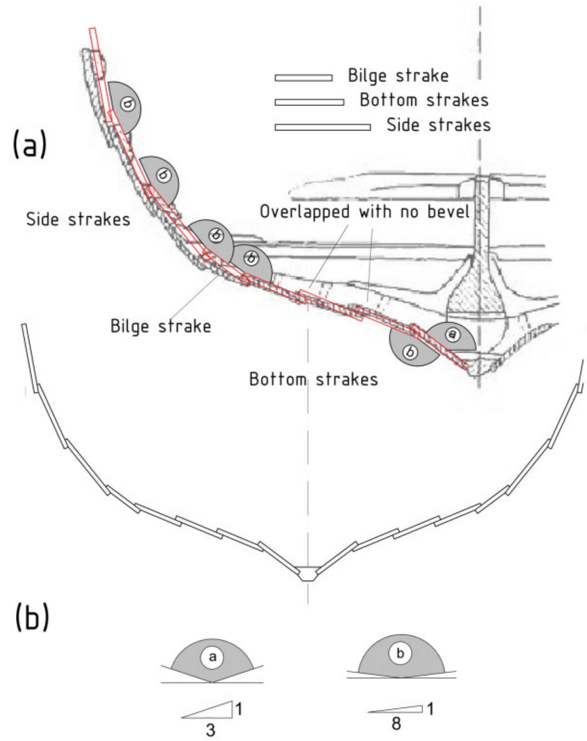

Figure 8. Master section of Skuldelev 3 with plank widths and bevel-gauges used to derive its shape. (Drawn by authors, over original by Crumlin-Pedersen and Olsen 2002: 229, fig. 40, with permission © Viking Ship Museum in Roskilde, Denmark)

available. There are two easily remembered bevel angles in the master curve (Fig. 8b): based on a 1-in-3 and a 1-in-8 slope. Using the bevel-gauge, the shipbuilder of Skuldelev 3 needed to remember just a few instructions to define the master section of the hull (Fig. 8). A single bevel-gauge may have been used to fix the angle between all the strakes that make up the hull. A different bevel is used to set the deadrise angle of the garboard.

The bottom is made up of four planks of similar width. The first two set the deadrise angle and the reverse angle that give a slight wineglass shape to the hull. The next two have no bevel between them; a common feature in clinker hulls. The next strake, the bilge strake, is the narrowest. It is where the hull begins to take a curved shape. It is followed by the sides which are made up of three wider planks. The strakes that make up the bilge and the sides have a bevel angle between them which could have been controlled with a single bevel-gauge (Fig. 8a).

This simple rule-of-thumb is easy to remember or can be recorded in a physical manner in a story-stick or 'recipe' (Fig. 6). Three linear dimensions for the plank widths, two bevel angles and the sequence of the use of the planks and bevels can easily be recorded on a board, or committed to memory, making this method suitable for use by illiterate boatbuilders.

Table 2. *Measurements of the internal width visible between each land taken from the 1/10 scale model of Skuldelev 1. *strake 4 curves strongly inward towards the keel between frame sections 3A and 2F*

Strake	4A	3A	0	3F	5F	Zone
Port sections						
			Width (mm)			
11	435	420	390	335	290	
10	450	465	455	435	385	Side
9	350	365	355	355	310	
8	270	260	310	295	250	
7	220	235	230	220	205	
6	210	235	215	280	205	Bilge
5	195	210	245	200	95	
4	255	260	210*	265	230	
3	210	230	250	220	220	Bottom
2	215	225	240	235	210	
1	195	210	225	165	135	
Starboard sections						
1	200	210	225	—	—	
2	230	245	260	—	—	Bottom
3	215	245	255	—	—	
4	255	250	270	—	—	
5	195	225	235	—	—	
6	230	225	—	—	—	Bilge
7	230	235	—	—	—	

Skuldelev 1, a medium-sized cargo vessel

The second hull belongs to the Skuldelev 1 wreck, a medium-sized cargo ship with a reconstructed length of 15.9 m and beam of 4.8 m. It was excavated as part of the same blockage as Skuldelev 3 in the Roskilde Fjord in Denmark. Dendrochronology showed that the wood used to construct the ship was cut *c.*AD 1030–1050 and originated from western Norway (Crumlin-Pedersen and Olsen, 2002: 136–40).

The analysis was again conducted on the primary data available for Skuldelev 1. The original paper reconstruction model, made to a 1/10 scale and kept at the Viking Ship Museum in Roskilde, was used to measure the inboard widths of the strakes (Table 2). The model was made by connecting the rivet holes of adjoining strakes with pins and thus is true to the archaeological material (Crumlin-Pedersen and Olsen, 2002: 121–2). The bevels were analysed from the reconstructed lines plan. Again, the cross-sections are used for illustrative purposes only and were not used in the analysis.

Rule-of-thumb for Skuldelev 1

From the plank widths (Table 2) and the reconstructed bevels (Fig. 9), it can again be concluded that

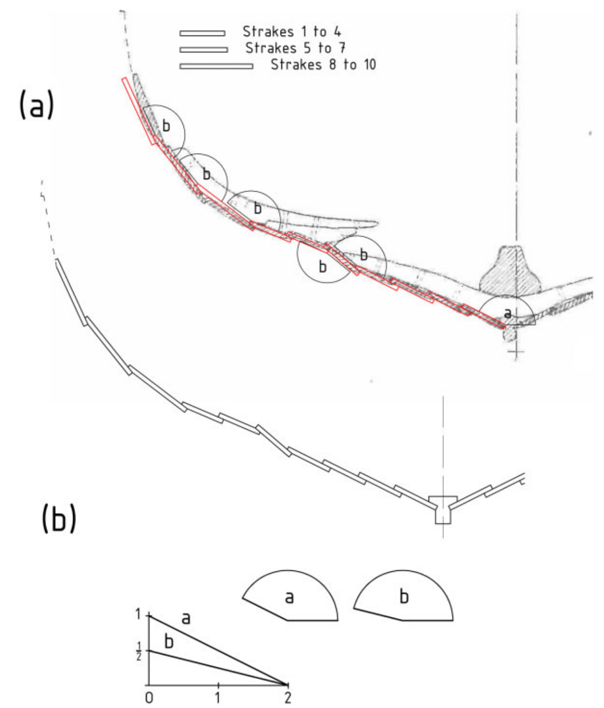

Figure 9. Master section of Skuldelev 1 with plank widths and bevel-gauges used to derive its shape. (Drawn by authors over original by Crumlin-Pedersen and Olsen 2002: 124, fig. 40, with permission © Viking Ship Museum in Roskilde, Denmark)

Skuldelev 1 was envisioned in three sections: bottom, bilge and sides. Each of the areas is planked with strakes of similar width (Table 2, Fig. 9a). Again, it should be noted that to produce Figure 9, the interior widths of the planks in the three zones have been averaged and a constant landing of 50 mm was added, as above. Two bevel-gauges obtained as a ratio of 1-in-2 and 1-in-4 are sufficient to define the shape of the master section.

If the hull had been built using a single virtual mould for the midship section only, it would be expected that the shape of the transverse sections would vary the further they are from midships. However, comparison of the shape of the sections with the master section (Fig. 10) shows that at several points the cross-sectional shapes of the hull could have closely matched the master frame. It can be seen that sections 4A and 3F, positioned relatively far from midships, could have had a very similar shape to the master frame; the difference is a narrowing towards the centreline. In order to superimpose the shape of the master frame on section 5F, it had to be narrowed towards the centreline, and scaled down; it is possible that the boatbuilder used the same rule-of-thumb as for the midship section, while reducing the breadths of the planks as they approached the ends of the hull, as observed in Table 2.

The accurate match between the midship section and sections 4A, 3F and 5F could be an indication that

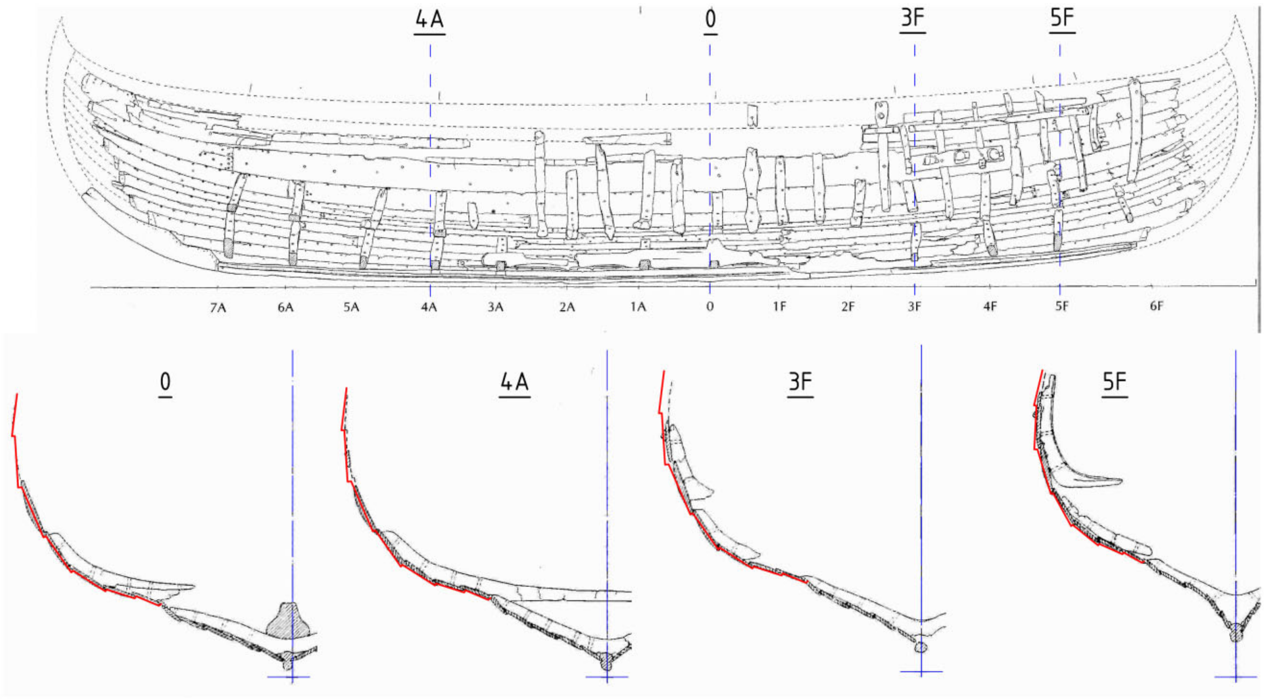

Figure 10. Comparison between master frame section and sections 4A, 3F and 5F. (Drawn by authors over original by Crumlin-Pedersen 2002: 124: fig. 40 with permission © Viking Ship Museum in Roskilde, Denmark)

the shaping of the hull was not something that happened as the hull was being built, but that it was a controlled process guided by rules-of-thumb that led the most important steps of its construction.

Longitudinal or transversal?

Admittedly, if one looks hard enough, rules-of-thumb can be devised for any shape or form. Therefore, the rules formulated above are no more than a hypothesis. However, there are a number of points that plead in favour of the proposed concept of mental templates in which such rules would have been stored.

First, the rules-of-thumb described above are very simple, easy to remember and offer a tangible and practical explanation of how a hull shape could be obtained and stored. They can be put into practice with the types of tools that boatbuilders in the Viking Age are believed to have used for the construction of their ships. Furthermore, they reveal how shipwrights could control proportion and form, even when building larger vessels such as Skuldelev 1.This in turn suggests how the confidence of those commissioning vessels could be obtained. Finally, it allows us to explain how knowledge of form and design could easily have been used as the basis for further improvement and transmitted to an apprentice.

The shipwright will produce an idea of the three-dimensional shape of the hull in his head, before he starts building. Proof for this can be found in the planks of a clinker ship. Not only will he be guided by rules defining bevels and strake widths, but he will also have an idea of the general shape of each plank. For example, the bottom planks will generally have a concave bottom edge, the bilge plank(s) can be roughly straight and the top strakes can have a broadly convex bottom edge (pers. comm. Fred Hocker, 2014). It has been argued that the precise and geometrically accurate shape of the plank-edges will be obtained during the process of hull construction using the rule defining transverse sections, and therefore do not need to be remembered or recorded (Figs 4 and 5). An understanding of the general shapes of the strakes before the erection of the hull is important and will help the shipwright in his choice of materials. Gently curving trees will be chosen for the planking and planks split from them will be used for different areas of the hull, depending on their natural curvature, facilitating the process of bending and twisting the plank into place. This shows that the longitudinal and transversal perspective would have very little meaning for a boatbuilder.

Practical knowledge in the Viking Age

In 1991, Govindan Parayil argued that the cognitive aspect is often overlooked in studies of technology. On a certain level, this is also the case for the study of the past ship technology. Although, since Hasslöf (1958) published his findings, much emphasis has been put on how shipwrights conceived their ships (Basch, 1972; Christensen, 1973; Gillmer, 1991; Hocker and Ward, 2004; Pomey, 2009), little attention has been paid to how the builders' knowledge was formed.

Our current view of Viking Age practical (shipbuilding) knowledge is determined by the way we think they built their boats; principally 'by eye' and with limited use of physical aids. If we recall Crumlin-Pedersen's description of clinker-building, the boatbuilder is presented as a 'sculptor', an exceptionally gifted craftsman that was able to give form to a hull 'by eye'. He attributes the great technological feats of these large Nordic ships to individuals with a great talent for preconception. Jörn Bohlmann (2012: 67) on the other hand, speaks of audio-tactile intuition and visual thinking; an implicit understanding of form. As a consequence, and perhaps intentionally, he described the process of conceiving the shape of a ship is described as radically different from modern construction and design.

The same is true for how the tacit knowledge of hull shapes is transmitted to apprentices. This is not easy to explain and often archaeologists cite the process of repetition of movements, without exploring what would be learned and transmitted in this way. Inspired by Eldjarn and Godal's famous ethnographic study on Norse vernacular watercraft (1988), Crumlin-Pedersen (2004: 50) states that age-old concepts would have been built into 'automatic' work procedures, almost of a ritual character, to ease the memorization process. George Indruszewski goes a step further and writes:

> 'The building process is characterised by a constant rhythm, which seen from outside might resemble what Godal called a kind of "ritual" with a "living rhythm". The learning-process consists of manual dexterity, body movements, processes and procedures, and less of techniques'. (Indruszewski, 2004: 239)

If the concept of mental templates in the Viking Age is generally accepted, this could be relevant for people looking at how knowledge is preserved and disseminated in a variety of fields. Perhaps this concept can help to further explore some of the topics discussed above; thus, it is worthwhile expanding on the concept of knowledge itself.

According to Schiffer and Skibo (1987: 597), practical or technological knowledge has three essential components: First, a recipe for action: the rules that underlie the processing of raw material into finished production. In other words, these are a series of steps that, if followed will result in a working finished product. It must be stressed that recipes for action are hypothetical models put forward by researchers on the basis of traces found on archaeological ship remains or based on the behaviour of people in the ethnographic record.

Second, a teaching framework: a series of practices that can include imitation, verbal instruction, hands-on demonstration, use of works of reference (drawings, tables of offsets) and even self-teaching by trial and error.

Third, the techno-science: the scientific principles that underlie a technology's operation. Techno-science accounts for why recipes for action lead to the intended product and why that product can perform its function(s). It is important to realize that artisans often practise their craft without any knowledge of the underlying techno-science. For example, it is doubtful that, even today, many bakers of bread understand the chemical reactions taking place when proving and baking; nor do they need to, as long as they have learned the appropriate recipes for action (Schiffer and Skibo, 1987: 597). The same is true for Viking Age boatbuilders. We do not know the extent of Viking Age knowledge of the mathematical principles used in naval architecture today; however their watercraft were very effective. There was no need to understand the techno-science; their recipes for action were well-developed and transmitted efficiently through a teaching framework. However, we must be careful not to portray boatbuilding as only a technical activity, unguided by theoretical understanding.

Accumulating, storing and transmitting

To move knowledge (a recipe for action), such as the form of a hull, from the moment and local site of its production to other places and times, knowledge producers, in this case the boatbuilders, deploy a variety of social strategies and devices for creating the connections between otherwise heterogeneous and isolated knowledge. This is a key element that would be missing if a hull shape were constructed 'by eye' and memorized. There is no cognitive device in place to store this newly acquired piece of knowledge. It remains heterogeneous and isolated within an individual's memory. The standardization and homogenization required for knowledge to be accumulated, stored and rendered trustworthy is achieved through methods of organizing its production, storage, transmission and utilisation. In addition to these social strategies, the linking of the heterogeneous components of a knowledge tradition may be achieved with a technical or cognitive device such as a mental template based on simple geometric ratios and rules-of-thumb (Turnbull, 1997: 553).

Geometry in mental templates

The essential ingredient in mental templates is geometry. This is the structural knowledge relating proportion and form of a hull shape to ratios. This sort of geometry is extremely powerful. It allows the successful repetition of a certain form in different places and circumstances, provides the basis for further improvement of the design, and enables the transmission of structural experience from master to apprentice. Most important of all, it reduces the number of solutions to a specific problem (Turnbull, 1993: 232). An example of such a problem could be the commission of a large cargo trader, fit to transport high-value goods across the Baltic. Of course, the shipwright will use previous experience in conceiving and constructing such a vessel. As a boatbuilder relying on mental templates he can also use rules-of-thumb based on geometry and passed on to him by his predecessors, working within the range of options that these rules allow. He thus follows a rule-bound, yet flexible, approach to such problems, open to improvement.

The learning framework

The simple geometric rules in a mental template suffice for the template itself to be accurately reproduced and transmitted as often as required. Therefore, the geometrical rules contained in a mental template help to make possible the training of large numbers of boatbuilders of varied skill levels over considerable periods of time (Turnbull, 1993: 232). It is thus not necessary to attribute exceptionally high levels of conceptualization and visual skill to Viking Age boatbuilders. Of course, an apprentice will learn the practical skills involved in working and shaping the wood by repeating technical movements over and again, as described by Crumlin-Pedersen and Indruszweski. Even the 'eye' can be trained and will become an increasingly reliable tool to judge lines, angles, and so on. Perhaps it can even be argued that, in time, an implicit understanding of form was acquired. But how will the apprentice learn the designs stored in the 'memory' of the master? The memorization of these designs as mental templates, each containing the rules for a certain shape, is one possible solution to this problem. Although they might have been written down on a 'story-stick' or equivalent, they need not have been recorded or even verbalized. The mental template can be transmitted by having an apprentice repeat a certain design. Bergson (2004: 113) called this 'habit memory': memories that are stored in the body as dispositions and habits. In contrast to so-called cognitive or recollected remembrance, habitual memories are lived and acted rather than represented (Olsen, 2010: 8). An often-used example of this is riding a bike, although swimmers also will be familiar with it. The learning framework for boatbuilders would then have consisted of a form of social organization, apprenticeship (however, see Ravn, 2014: 121–30 for more detail on communities of practice), and a simple memorization tool; mental templates, stored in a variety of possible ways. The ways in which this kind of knowledge was transmitted might thus very well look like a sort of ritual to the eye of the modern western observer, however this ritual should be seen as the method used to teach both technical skills and pass on experience and knowledge of tested designs in the form of mental templates.

Synthesizing theory and practice

The concept of mental templates manifests the integration of practice and theory, without the necessity for techno-science. It shows that the construction of Nordic clinker-built ships does not need to be the product of abstract and high-level conception, nor should it be seen as only a practical matter. It required a basic understanding of proportional analysis and a minor innovation in conceptual thinking, a recipe for action. This happened inevitably within a craft tradition, the work of other boatbuilders, and a *habitus*, the prevalent socialized norms and tendencies that guided the behaviour and thinking of these shipwrights. They operated, not according to some set of universal principles of logic or method, but to local judgements and negotiations which include not just cognitive and technological concerns, but also purpose, available materials, environmental and ideological factors and economic interests (Turnbull, 1997: 555; Adams, 2003: 24–9). The 'Nordic style' as such was not in the minds of these boatbuilders. The idea of a particular style implying a unifying set of rules or principles is a construct of current-day archaeologists. The concept of tradition is more fluid; it is a system of ideas of what boats and ships are, something which will inevitably impact on ideas of how they should be designed and constructed. This is why for example, a Danish traditional boatbuilder, given the rules-of-thumb used to build a shape common to western Norway, will build a different boat than a traditional western Norwegian boatbuilder would.

Describing Viking Age boatbuilders as just skilled workmen is doing them an injustice as it implies a separation between theory, design and practice. This is a modern notion inspired by the separation of execution and design which developed from the 15th century onwards. As theory and practice were uniquely synthesized in the knowledge and skill of the Viking Age shipwright, a more suitable term would be 'master boatbuilder', analogous with the master masons of the 13th century (Turnbull, 1993).

Conclusions

Detailed examination of the transverse sections of Viking Age hulls, using the published ethnographic material and the analysis of the available primary data for Skuldelev 3 and Skuldelev 1, has demonstrated that simple and easily remembered rules-of-thumb, based on bevel angles and strake widths, together defining transverse sections, could have been used to control the transverse shape of the hulls of these ships. The concept of mental templates, defined as a series of rules-of-thumb wherein a master boatbuilder could store and transfer knowledge of how to obtain the form and proportions of a certain hull shape, has also been explored. Rules to define the shape of stems, transversal sections and information such as the rough shape of a strake could all be incorporated in a boatbuilder's mental templates, thus rendering the distinction of longitudinal and transversal perspectives, from the viewpoint of the shipwright, moot. Furthermore, it is argued that the 'eye' of the boatbuilder and his mental templates are inseparable, work together and are of equal importance when constructing a Viking Age ship.

The concept of mental templates, which facilitates the accumulation, storage and transmission of practical knowledge, helps to further understand how knowledge is preserved and disseminated. Thus, it is argued, it is not necessary to attribute exceptionally high levels of conceptual capabilities to Viking Age shipwrights.

Mental templates allow knowledge to move from the moment and locality of its production to other places and times, and are excellent cognitive devices to create connections between otherwise heterogeneous and isolated knowledge. Furthermore, practical geometry would have been an essential mechanism in the toolbox of the Viking Age master boatbuilder. It allowed him to successfully repeat working forms in different places and circumstances and to communicate his structural experience to an apprentice or other boatbuilders. Most importantly, it reduced the number of possible solutions, the infinite number of hull shapes for a specific problem or commission.

The process of learning how to construct a form or hull shape has been considered. Using the social strategy of apprenticeship and a memory tool such as mental templates, a framework of knowledge containing the rules-of-thumb for various hull shapes can be transferred to an apprentice. This, in addition to the technical and practical skills the apprentice attains through assisting the shipwright. Finally, the work of the Viking Age boatbuilder is an ideal example of the synthesis between design and practice. This is lost in modern-day engineering where the architect designs and the worker builds according to the architect's instructions. However, this unique skill set can still be observed in the craft and practical knowledge of the Viking Age master boatbuilder.

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