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Ricardo Nemirovsky
Professor
Manchester Metropolitan University
r.nemirovsky@mmu.ac.uk

Stephanie Bunn
Associate Professor Emeritus
St. Andrews University
sjb20@st-andrews.ac.uk

Francesca Silverton
Ceramic Artist
Morley College
f_silverton@yahoo.co.uk

Crafts and the Origins of Geometry

ABSTRACT
In this paper, we explore the possible roles of craftwork in the origins of geometry. Because shapes are the characters of geometry, our focus is on crafting solid shapes. We characterise the becoming of a shape or form as its 'shaping', which includes preparation of materials, development of skills, making with tools and equipment and the subsequent life of the shape or form through use and exchange. From studies on prehistoric pottery, we explore a conception of 'shaping' as thoroughly implicated by the manifold social, biological and material lives of communities in mutual contact. Processes of shaping are at once—inseparably—material and imaginary. We make shapes as they shape our bodies, which then enable us to imagine and gesture them.

Keywords:
Time space, Reconstruction, Material culture, Craft impact, Societal strategies.

INTRODUCTION

In 1938, Husserl (1989) articulated a perplexing status for geometry and, more generally, for mathematics in our era:

> The progress of deduction follows formal-logical self-evidence; but without the actually developed capacity for reactivating the original activities contained within its fundamental concepts, i.e., without the 'what' and the 'how' of its prescientific materials, geometry would be a tradition empty of meaning. (p. 169)

What are these original activities, or primal sources, as he also called them, that need to be 'reactivated' for meaningful encounters with geometry? Among all possible original activities, Husserl (1989) emphasised what we might call craftwork. As opposed to only noticing shapes and patterns present in the

environment, craftwork—a synthesis of functionalism and aesthetics—involves making them through the collaborative use of bodily skills, suitable tools and material transformations in concert with complex measurements and socio-ritual meanings. Even for a straight line, one of the most basic mathematical concepts, there is a world of difference between the experience of just seeing it (e.g. a rope holding a heavy object) and of making it, whether by drawing, folding a piece of paper or stretching a string. Mathematical shapes and patterns are likely to share common origins with crafted shapes and patterns, which, according to many anthropological studies, are of spiritual and cosmological significance.

The ideas discussed in this paper emerged from the work of the Forces in Translation project (https://forcesintranslation.org/gallery/). For several years, this project has supported the development of a small community that includes basket weavers, anthropologists and mathematics educators. While the members of this community represent a variety of personal backgrounds, ages and life stories, they are primarily united by their senses of wonder, solidarity and mutual respect. Crucially, all the members are presumed to be equally capable of making sense of new questions and joint explorations of crafts and mathematics. We gather regularly to engage in studio practice and the anthropology of crafts. With an emphasis on basket weaving, we conceive of a studio practice as a working space in which participants share and learn craft skills, make things, examine baskets made at different historical times and study and discuss related topics from mathematics and the anthropology of crafts. Studio practices have been set up both onsite and online. A subset of studio practices has been opened to the public, hosting family groups, craftworkers, graduate students, museum curators and mathematics enthusiasts. These long-term collaborations have been fertile grounds for ideas and craft learning, including reflections on the possible participation of crafts in the ancient origins of geometry.

The paper is divided in four sections. Section 1 (Crafting Shapes) outlines how we use the terms ‘shape’ and ‘form’. Section 2 (Craft and the Philosophy of Shape/Form) elaborates on the concepts of hylomorphism, workmanship of risk, and workmanship of problem-solving. Section 3 (Shaping *Depas*) explores the archaeology of a ceramic vessel used in Anatolia and the Aegean during the Bronze Age. Section 4 (Shaping and Geometry) discusses the relationships between shaping and geometrical work, and describes the making of a dodecahedron by a participant in a ceramics workshop.

Crafting Shapes

In this section, we elaborate on the arts of crafting shapes and their sociocultural, historical and material implications. In English, ‘shape’ and ‘form’ have overlapping meanings, and we are frequently free to exchange them. However, as we elaborate here on the plausible origins of geometry, it seems more proper to use ‘shape’, given that when describing a geometrical entity, such as a cube, we are likelier to refer to it as a shape than a form. Nonetheless, in this paper, we use both ‘shape’ and ‘form’, although the pervasive polysemy of words requires us to clarify what we mean when we use either term. While ‘shape’ often connotes the surface or outline of an object, in this paper, shapes shall be understood as multidimensional. For example, Figure 1 depicts a wheel-made pot in one of the ways that such pots are regularly portrayed in archaeology articles. As a solid object, this pot is three-dimensional in the sense that all its parts have the depth indicated by the spatial distribution of materials. However, it is also two-dimensional because it includes multiple surfaces, and one-dimensional by virtue of the infinite contours and outlines that can be traced over it. Another caveat is that we will work hard not to detach ‘shape’ from all the qualities (e.g. texture, colour or usage) inherent in the actual pot; this lexicographic choice may be a bit difficult, but it is necessary to make ‘shape’ a term encompassing all the socio-cultural, climatical, geological and economic aspects participating in its formation and use. To emphasise this, we will regard shapes as individuals. However, as not all individual things have inherent shapes (e.g. liquids tend to adopt the shapes of their containers), we tend to think of shapes as solids.

FIGURE 1. Wheel-made pot from the late Bronze Age IIB (1300–1200) (Choleva, 2020, p. 68).

An online dictionary begins to describe the etymology of the verb 'shape' in relation to creating and forming: 'create, fashion, form (Middle English *shapen*, from Old English *scapan*, past participle of *scieppan*); form, create, make out of existing materials; bring into existence; destine' ("shape," n.d.a). These etymological roots point to a direction very different from that to which the following Wikipedia entry for the noun 'shape' points: 'a shape or figure is a graphical representation of an object or its external boundary, outline or external surface, as opposed to other properties such as colour, texture or material type' ("shape," n.d.b). While the former suggests processes of making that bring things into material existence, the latter focuses on representing forms and removing all qualities except external boundaries or surfaces—a notion of shape focused on externality and looking from a distance. How can we understand the radical divergence between these two approaches to shape? Ingold (2013) orients us towards such understanding by pointing out that this is, in part, a divergence we find everywhere in linguistic expression:

> Much can ride, in English, on the indefinite article. Building is an activity; it is what builders do. Add the article, however, and the activity is brought to a close. Movement is stilled, and where people had once laboured with tools and materials, there now stands a structure—a building—that shows every sign of permanence and solidity. (p. 47)

To emphasise the aforementioned difference, we distinguish between 'shape' and 'shaping'; the former refers to something solid in static fashion, while the latter refers to something in formation. With 'shaping', we want to allude to the processual genesis of something solid both as it becomes and as it changes through use and exposure. Figure 1 shows the shapes of a pot made during the Bronze Age. This is a representation that excludes all aspects and processes that shaped it: activity is brought to a close. Implicit in this display is the sense of a frozen end, as we see a pot in a seemingly final and static shape. Figure 2, on the other hand, shows images of the hands of a potter at work. These images not only show hands shaping clay but also reflect a shape in formation, loosely organised across time. Rather than a finished jar seen from a distance, it foregrounds an ongoing active touch engaged with the forces and initiative of clay.

FIGURE 2. Hands of a potter at work (Malafouris, 2008, p. 20).

Any image can be seen according to differing perspectives. For example, a skilled potter may feel the pot in Figure 1 as immersed in complex shaping processes, going beyond visual apprehension, perceiving it with the whole body and sensing certain kinds of clay at work. Conversely, a technical draftsman may focus on the last image in Figure 2 to draw an external static and proportional contour. What we are trying to foreground is not the intrinsic character of each image but divergent ways of conceiving the nature of making, for which some imageries are more expressive than others. A technical draftsman may lament the inexpressiveness of Figure 2 in that the images are blurred and of a very low resolution, whereas a skilled potter might wish that Figure 2 consisted of a video instead of a sequence of discrete stages silencing how they transform into each other continuously. The expressiveness of an image can differ dramatically depending on the skills and orientations of the perceivers.

We surmise that not all craftwork amounts to making things with solid shapes (e.g. cooking soup may not), but a large proportion of it does. Depending on the craft, shaping may incorporate countless types of processes. For instance, some craftworkers (e.g. wood carvers) shape by subtracting material from an initial chunk, while others (e.g. basket weavers) work by adding material to evolving structures. In some cases, shaping takes place through continuous deformation (e.g. potters), whereas in others, it takes place through the discrete assemblage of building blocks (e.g. bricklayers). We propose that all these divergent processes are distinct ways of shaping something in the context of various craft practices. Given the ancientness of early geometry, its origins must have been prehistoric. This has motivated us to choose prehistoric pottery as a source of examples and cases on which to reflect; however, we also have recourse to prehistoric pottery to illustrate processes of shaping across many types of craftwork and eras. To convey generality through cases, we next elaborate on aspects of the philosophy of shape and shaping, or form and forming.

Craft and the Philosophy of Shape/Form

An important conception has been developed by Aristotle postulating that all objects and organisms are composed of two inseparable 'principles': matter and form. Matter is passive but bursting with potentiality. Form is the active principle that determines what a lump of matter comes to be. Aristotle used the matter and form principles to explain an extremely broad range of phenomena:

> [Aristotle] differentiated the sublunary world from the celestial one by noting that celestial objects had forms, but no earthly matter. For living things he identified their form as their soul and their body as their matter. [...] Matter and form were among the basic concepts needed to understand change, which

> Aristotle described as a transition in matter from a state of privation to the presence of a specific form, or vice versa. Difficult as it may be to imagine now, even change of place was conceived in this way: the 'natural place' sought by a falling body was determined by its form. (Manning, 2013, pp. 173–174)

Some of the aforementioned pluralistic and metaphysical conceptions are now called hylomorphism, from the Greek words *hyle* (matter) and *morph*e (form). The term 'hylomorphism', unused by ancient Greek philosophers, has become well known since the beginning of the 20th century (Manning, 2013). Given the great variety of uses of the principles of matter and form throughout antiquity, it is more appropriate to talk about hylomorphisms as a plural term. Over the last two decades, there has been a resurgent interest in hylomorphisms within analytical philosophy (Simpson, 2023). One hylomorphism with special relevance for the analysis of craftwork can be characterised by certain Aristotelian examples, such as a bronze statue, as it has come into being through the transformation of a lump of bronze (matter) into a statue (form):

> If we say that a statue is made from bronze and a bed from wood, and so on in all the other cases where we say that the thing made is made from a material, meaning that the whole is formed from something preexisting *which is only put into shape*. (Aristotle, De Gen. Anim. A 18, 724a20, italics added)

This kind of hylomorphism has been subjected to an influential critique by Simondon (2020), which, in turn, has inspired significant commentaries by, among others, Deleuze and Guattari (1987), Ingold (2013) and Malafouris (2013). Simondon's (2020) primary example is brick making by pouring clay into a mould and letting it dry. It is useful to distinguish three kinds of phases in brick making: (1) preparatory phases for the clay and the mould, in which the mould is made and coated and the clay is transformed into a homogeneous plastic colloidal; (2) phases starting with the pouring of the clay into the mould and ending with the detachment of the brick from the mould and (3) phases of finishing, usage, maintenance and return to earth. Simondon (2020) questioned hylomorphism by claiming that it misses two fundamental processes intervening in brick making: (1) preparatory work on clay and mould and (2) the synergetic confluence of clay and mould into a concordant mix-up or entanglement of materials, tools and craftwork, *within and across* which the brick emerges shaped/formed:

> The hylomorphic schema corresponds to the knowledge of someone who remains outside the workshop and considers nothing but what enters and exits it; in order to know the true hylomorphic relation, it is not even enough to enter the workshop and work with the craftsman: we would have to penetrate into the mold itself in order to follow the operation of form-taking on the different scales of magnitude of physical reality. (p. 30)

To such an outsider, processes like the prior gathering, drying, crushing, sifting, wetting and kneading of clay, or the manufacturing of the mould, are unnoticed. Further, the integration of hands, skills, matter, minds and tools in the workshop, all pervaded by flows of energy, weather and attention, is confined to a black room, from which the formed brick appears. We will call these unheeded phases within the workshop 'forming'. Forming consists of those phases coalescing everything in the workshop. The tools, craftworkers and materials in it are not parts-extra-parts but conform to an organic unity traversed, at different scales, by common flows. It is not an inter-action between clay and mould but an intra-action of unlike elements unified in such a way that they become pluri-functional at diverse scales, belonging to an all-encompassing medium shaping the brick.

> The action of the worker who fills the mold and packs the clay continues the prior action of kneading, stretching, and shaping: the mold plays the role of a fixed set of modeling hands, acting like halted kneading hands. (Simondon, 2020, p. 25)

Malafouris (2008) coined the term 'hylonoetic'—joining the Greek *hyle* (matter) and *nous* (mind)—for a perspective that fills the gaps left unattended by the hylomorphic scheme. Hylonoesis elucidates how each brick becomes a unique individual, not only because it gets shaped somewhere at a certain time

but also because it emerges from the singular histories of, among others, the mould in use, the skills of the involved craftworkers, the geology of the deposit from which clay had been extracted and the prevalent weather throughout its shaping. While this was clearly the case for prehistoric production, we think that something important must be different in the case of contemporaneous mass production. To detect individual differences, for example, after the mass production of plastic cups, we would need to examine their molecular structures. Furthermore, the production of integrated circuits is based on the industrial generation of identical silicon crystals, and identical crystals do not exist in a natural state because of spontaneous irregularities. Thus, not even the examination of their molecular structure will serve to discriminate between unique individuals.

How to think of the major differences between artisanal and industrial production? Simondon (2017) characterised these along a line of progress, tracing evolutions from abstract to concrete processes: artisanal production is abstract and primitive, while industrial production is concrete and advanced (p. 29). We move away from such a conceptualisation and work to grapple with how, especially during the forming phases, the artisan and her equipment face an ongoing flow of improvised material responses that constantly call for improvisation on their part. Improvisation is a skilled performance; without skill, the maker cannot respond to and feel material activity in a nuanced and sensitive manner. At the same time, skilled improvisation emerges from ongoing present circumstances that are always open to subtle, unexpected events. To delineate such mutually improvisational intra-actions during the forming phases of an artisanal product, we will summon a couple of ideas that have been introduced by students of craft practices: workmanship of risk (Pye, 1995) and workmanship of problem-solving (Marchand, 2016).

> [Workmanship of risk is] the use of any kind of technique or apparatus, in which the quality of the result is not predetermined, but depends on the judgement, dexterity and care which the maker exercises as he works. [...] We may contrast it with the workmanship of certainty, always to be found in quantity production, and found in its pure state in full automation. (Pye, 1995, p. 29)

While workmanship of risk seems to implicitly emphasise risks of failure as inherent in craftwork, workmanship of problem-solving foregrounds possibilities of innovation always present in artisanal production. For the most part, such problem-solving does not involve the craftworker stepping back from making to thinking about it; rather, it is problem-solving while shaping is ongoing and is posing problems that need to be addressed on the fly:

> From this perspective, creativity should not be understood as the making of unique forms and images. Instead, the artisan's creativity is an open-ended process of *continuous* negotiation with materials as an integral part of practice. [...] The process of craft is therefore one of constant problem solving in the face of materials and tools that are never fully under the artisan's control. (Gowlland, 2016, pp. 185–186; italics added)

We propose that, most prominently, what distinguishes artisanal production from mass production is that in the former, the shaping capacities of craftworkers, their equipment and the participating materials are amenable to workmanship of risk and workmanship of problem-solving. This is a difference not unlike that between live music and playing recorded music. In live music, the musicians wield workmanship of risk and workmanship of problem-solving on an ongoing basis. While many listeners of recorded music may also practice these two types of workmanship, particularly if they are musicians themselves, in the case of live performance, the forming processes of music are open-ended and inclusive of the performers, audiences, instruments, moods and the exercise of numerous skills, all of which are likely to foster a more intense emotional turmoil. We refer to mass production in the cases of automatized manufacturing of, for the most part, identical products through identical processes. An emerging type of production is neither artisanal nor mass production; it uses radically pluriversal technologies, such as 3D printing, in conjunction with artificial intelligence software allowing for the generation of diversified products involving inhuman processes of risk and problem-solving.

FIGURE 3. Depas Amphikypellon (ancient Greek: δέπας ἀμφικύπελλον; plural *depata*), from Poliochni on Lemnos, Early Bronze Age (3rd millennium BC). National Archaeological Museum of Athens. From https://en.wikipedia.org/wiki/Depas_Amphikypellon

Returning to the idea that each brick is unique as it emerges from the singular histories and circumstances of all the constituents of the making process, bricks produced in a certain artisanal workshop may also have many traits in common. They may all be approximate parallelepipeds, with similar colour tonalities, linear measurements or weights. These collective features are regularly seen as describing their designs. Like 'form' and 'shape', 'design' is used in innumerable ways. Pye (1995) wrote that 'design is what, for practical purposes, can be conveyed in words and by drawings: workmanship is what, for practical purposes, can not' (p. 17). Something that we like about Pye's definition is that it implies that a design does not have to pre-exist (in words or images) the crafted product, whose design emerges, at least partially, during the making processes themselves. For example, the colour of a vessel is often unreliably determined by the firing process but can be said to have been designed (i.e. as it can be conveyed, after the fact, in words and images) through the workmanship of risk. It is commonly thought that a design is generated in the mind of a person, such as a maker or designer, and yet we think that this is an empty statement. What do we learn by saying that designs are mental entities? In the next section, we elaborate—again in the context of prehistoric pottery—on the sources or springs of a design, as they extend in a rhizomatic fashion across social, cultural, economic, material and migratory currents, encompassing patterns of use, dissemination of traditions, development of skills, technology diffusion and commercial networks. To do this, we use a particular shape, currently called *depas*, which

was widespread in the Near East, especially in Anatolia, during the Bronze Age. Unless a different citation is added to the text, the information in the next section was taken from Şahoğlu (2014).

Shaping Depas

Depata were drinking vessels common in Anatolia and, somewhat later, in the islands of the Aegean during the Early Bronze Age. Although no metallic *depas* has been found, based on some of the groove decorations, form and other details, it is widely believed that ceramic *depata* were copied from metallic ones at least initially. It seems that clay vessels emulating metallic ones were relatively common then, possibly because they were cheaper, because skilled potters were much more widely available and because clay was accessible. *Depata* were predominantly shaped with the rim opening outwards, the main body close to cylindrical, with a small base (often pointed) and two large vertical handles. They were burnished on their exteriors and on the interiors of their rims. In most cases, they were produced locally rather than imported from afar. The appearance of *depata* coincided with the spread of an important commercial network—the Anatolian Trade Network—and of new styles of eating and drinking, which included wine consumption. The characteristic inclusion of two large vertical handles has been seen as suggesting collective usage, such that everyone sipped from it and then passed it to a neighbouring person. This custom would have been coherent with *depata*'s small or pointed bases because these made them unsuitable to rest on their own, on a table or on the ground, making it imperative to fully consume the drink at once. An alternative might have been to place a ring of fabric or ceramic at the base of a *depas* to keep it stable; some examples of these *depata* have been found. In any case, the possibility of collective usage and the fact that *depata* have been found in funerary pits hinted to archaeologists that at least some *depata* had ceremonial uses and would have marked prestige and status. Şahoğlu (2014) hypothesised that *depata*'s use by traders travelling along the Anatolian Trade Network accounts for their large geographical distribution. In addition, the two handles could have allowed the *depata* to be hung with a rope from the person or pack animal instead of occupying precious space within the transport sack.

Regarding information on the making of *depata*, we rely mainly on Choleva (2020). Her study was mostly based on the Aegean islands and the Greek mainland, but she focused in detail on the technologies used by potters:

> The earliest evidence for the use of the potter's wheel in the Aegean is documented during the late EDII (c. 2550–2200 BC) [contemporaneous with the Anatolian Trade Network]. This period is characterized by profound changes in material culture [...] including processes such as early urbanization, the expansion of fortified settlements, the exploration of metal sources, the increased development of craft specialization in metal industries and pottery production. (p. 64)

It was also during the aforementioned period that 'a new set of eating, drinking, and serving pottery' (p. 64), originally from western Anatolia, became fashionable. This new tableware included *depas* as a late addition. Hand-forming techniques were predominant for all pottery styles, but the potter's wheel was used exclusively for the new tableware, which included *depata* and other pots, and never for 'traditional Aegean shapes and wares' (p. 95). During this period, potters used the wheel in combination with coiling. This process, called wheel-coiling, is different from wheel-throwing, which is illustrated in Figure 2. Wheel-coiling involves the use of a relatively slow rotary device in combination with coiling. Coiling encompasses four main hand-shaping activities: (1) building coils; (2) joining coils; (3) thinning the walls and (4) shaping the walls. Wheel-coiling methods include the use of a wheel for one or more of these activities. For instance, in one method, the potter used the wheel only to shape the walls (see Figure 4).

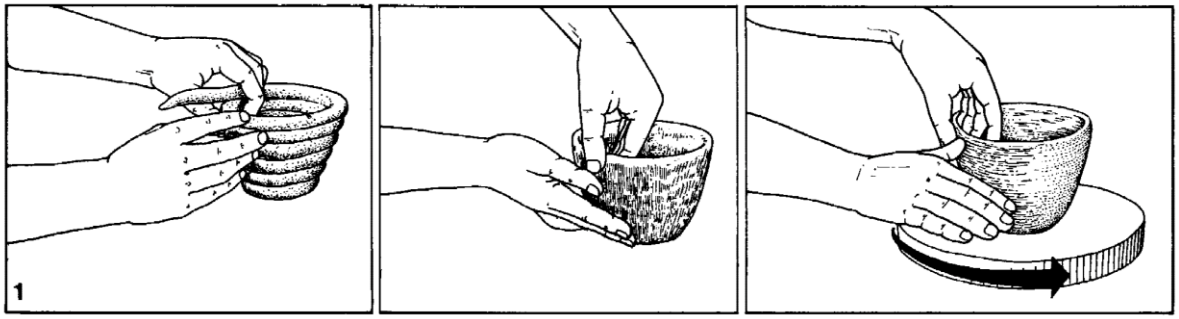

FIGURE 4. First method of wheel-coiling from Roux and Courty (1998, p. 749).

Given that wheel-coiling involved not only the use of the wheel but also the development of sophisticated new skills, the following can be said:

> [Wheel coiling] emerges as one of the many ways of making the new pottery [including *depas*] suggestive of the cultural habit of a few potters sharing a unique and complex forming technique of western Anatolian origin. […] Specialist potters seem to have been dispersed across the Aegean and created sporadic networks of apprenticeship that ensured the reproduction of their craft (Choleva, 2020, p. 96).

Different shapes of *depata* were characteristic of each region. Figure 5 illustrates three of them. Type 1 was the most common: the small base was flattened, and it had a height of 10–20 cm. Type 2 had an S-profiled curving body, its height was 15–20 cm, and it had a red-painted vertical band on the body. Type 3 had a fluted decoration on the body and a height of 10–28 cm. Particular decorative elements, such as a vertical colour band or fluted horizontal lines, served to identify the regions of origin.

The diversity of designs for what counts as a recognisable kind of drinking vessel—*depas*—suggests how pottery shapes are commonly coupled to categories inclusive of many variations. A given type of *depas* might have included, among others, a range of heights, outlines, distinct fluted lines, weights and silt colours. There are some features—such as the two large vertical handles or the small base, as well as same uses, such as drinking from the *depas*—that remain invariant unless they are treated as 'exceptions'. This is, of course, a fundamental feature of geometric shapes. Squares, for instance, can be of very different sizes and orientations without losing their squareness.

FIGURE 5. Some types of *depata* from Anatolia (from Şahoğlu, 2014).

Let us return to the genesis of designs. Our brief overview of the making and circulation of *depata* illuminates how, rather than being generated in the mind of a designer or potter, each *depas*'s design materialised 'as a process of growth':

> This is to place the maker from the outset as a participant in amongst a world of active materials. These materials are what he has to work with, and in the process of making he 'joins forces' with them, bringing them together or splitting them apart, synthesising and distilling, in anticipation of what might emerge' (Ingold, 2013, p. 21)

We add that design not only results from the initiative of active materials but also from travelling with the wheel, bartering vessels, dwelling in traditions, training and being trained, and dealing with community lives, geographies, consecrating rituals, drinking habits, the pull of gravity and more. In critical ways, all of them are co-designers.

Once a *depas* leaves the potter's workshop, it stands ready for an independent life of holding, pouring, waiting, dangling from ropes, enduring injury, exchanging, travelling and so forth. During all of these processes, it becomes what Heidegger (1971) called 'a thing'. As a thing, a *depas* is an endless and unique gathering of stories, events, drinks, traces, habits, owners and seasons. Over a *depas*'s life-as-a-thing, it reveals the shape/form of a *depas*, not in the Platonic sense of an idealised figure emulating its outward appearance but in the Heideggerian sense of giving, receiving, filling and emptying. During its life, manifested by its capacity to stand on its own, a *depas* is dependent on caring hands and ropes. Moments of carelessness risk a *depas* falling, which could break it into pieces, possibly initiating its slow return to earth.

Shaping and Geometry

Shapes are the characters of geometry. As Husserl (1989) lamented a century ago, standard contemporary perspectives assimilate geometric shapes into things that are out there and prone to be treated as inert, ready-made templates. The liveliness of geometry can be nurtured only with animated shapes immersed in the vagaries of materiality, full of secrets and longing for their open realisation, one that is at once—inseparably—material and imaginary. The fusion of materiality and imaginaries arises from the bodily, gestural and social making of things—in other words, from shaping. We make shapes as they shape our bodies, and then we become capable of imagining and gesturing them. Only when shapes are granted lives of their own can we hear them telling us remarkable stories. Try to draw a circle on a piece of paper with a pencil rather slowly so that you can be mindful of the process. If you allow yourself to merge materiality and imaginaries, you might notice, as you draw it, that the circle-in-the-making is pushing your hand and pencil in certain ways. Contemplating the drawn circle, you may observe that certain parts could have been more circular; furthermore, these deviating parts may have been prompted by variations in the process. For instance, your hand might have occluded the tip of the pencil, or your holding of the pencil may not have been suitable to trace them. New bodily skills are called for, skills that could allow us a sensibility more attuned to the needs of a circle. You will find yourself engrossed in never-ending trade-offs, such as finding that a larger circle could be more precise in some ways than in others. The overall sense is that a circle—any circle—has its own ways of going to which we, our bodies and our tools can be more or less sensitive. It is true that a circle in a geometric diagram can be studied simply by hypothesising that it is a circle, regardless of all its drawn 'imperfections'. However, such hypothesising endows the drawn circle with traits it wished in its own making, such as a constant curvature, and this has strong implications for how we fuse material and imaginary processes in examining and gesturing it. In other words, what may seem just an act of fiat ('this is a circle'), almost as effortless as creating something ex nihilo, carries extraordinary implications for what we do with and say about it, and these implications stem from the material/imaginary processes of making a circle. It is in the material/imaginary shaping of a circle that we sense what it cares about.

In his discussion about different types of lines, Ingold (2013) characterised the geometrical or Euclidean line as one that is plotted between two points, which was 'eventually divested of all remnants of tactility' (p. 134). We agree that such divestment marks what the Euclidean line has largely become, a representational convention that has lost all signs of life. However, it was not always that way. Draw two tiny points on a piece of paper and try to draw, rather slowly, a straight line intersecting them. You may start from one of the points and try to get to the second one without curving. How do you manage to do it? Are your fingers inert and rigid? On the contrary! Ongoing subtle adjustments are improvised

along the way; they are needed not only because slight departures from straightness are unavoidable but also because the arrangements of the arm, hand, pencil and fingers are always in the process of mutual adjustment. Once the line goes past the second point, the skilful enactment changes because there is no longer any point towards which to stay oriented. It is then the recent past of the line that helps us keep going. We may think that such skilful mindfulness is unnecessary in the case of drawing a line with a ruler. First, this is not entirely true. How we hold a pencil, in what angle we hold it with respect to the edge of the ruler, how sharp the pencil is and how we position the ruler next to the two points all matter in the making of a line. More importantly, though, with a ruler, we are making a line by copying a given straight edge. The relevant issue then becomes how to make a straight edge. The shaping of a straight edge is an ancient challenge. It is the nature of this challenge that is likely to have inspired ancient Greeks to define a straight line as follows:

> The only definition of a straight line authenticated as pre-Euclidean is that of Plato, who defined it as 'that of which the middle covers the ends' (relatively, that is, to an eye placed at either end and looking along the straight line). It appears in Parmenides 137 E: 'straight is whatever has its middle in front of (i.e., so placed as to obstruct the view of) both its ends'. Aristotle quotes it in equivalent terms. [...] Proclus also quotes the definition as Plato's in almost identical terms. (Heath, 1925)

Looking at an edge by observing one of the end points and orienting the edge to minimise its visual extension has traditionally been a way of assessing its straightness and finding areas of the material piece that require further polishing. Interacting with shapes, including straight lines, as inert and dead things turns geometry into a dead thing as well, which, unfortunately, is how many students experience geometry. We conjecture that the personality, so to speak, of a shape is not to be found in ready-made templates but in engaging with its multifarious and always-unfinished shapings—in other words, in the ongoing joint skilful play of materials and bodies. To share an example of such engagement, photos of two pieces of clay made during a one-day workshop conducted by the ceramist Francesca Silverton, which was attended by graduate students and novice students of ceramics, are shown in Figure 6.

FIGURE 6. A semi-sphere and a dodecahedron made during the workshop.

In the morning, the participants were each given approximately 500 g of clay for an exercise involving making two pinch pots. They were shown how to shape clay into a ball the size of their palm and hold it in one hand. The other hand was used to make an indentation using the thumb, while the clay ball was repeatedly turned using the outside fingers. As the clay was turned, the thumb was to continue to make a deeper indent inside the clay ball; this would shape the clay into a vessel form. Meanwhile, the outside fingers would continue to gently squeeze the clay walls higher, further developing the vessel form. The participants were asked to keep the top edges of both of their pinch pot vessels at least 1 cm thick. This would allow the two halves to be joined together at their edges, forming a spherical shape. The clay edges were gently scored using either a potter's needle tool or a feather wire tool (see Figure 7). The scored edges were brushed with a mixture of clay and water, with a double cream consistency, to create glue allowing the two edges to attach.

FIGURE 7. Potters' needle tool (above) and feather wire tool (below).

Some participants left the sphere alone, just making a small hole to release air. Others developed their spherical forms in different ways, such as by slicing and cutting or by slicing away the top of the spherical form and pinching the walls to make a larger vessel. They were encouraged to decorate the sides of their work, making use of the textured materials brought to the workshop for this purpose.

In the afternoon, the participants were given several template nets on paper to choose from. See Figure 8 for two examples. Thin slabs of clay were prepared by rolling between two batons of equal height. Individual elements from the templates were placed on the flat clay and used to guide the cutting of the clay with a knife.

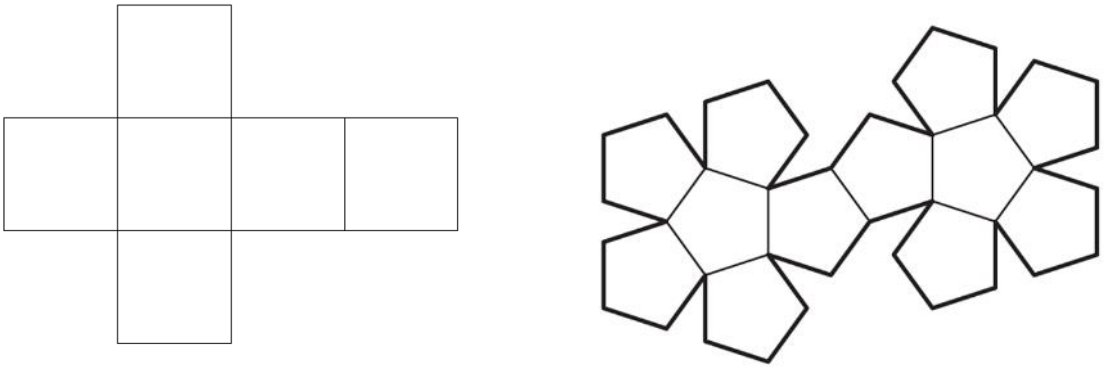

FIGURE 8. Template nets of a cube and a dodecahedron.

To make a dodecahedron, Teresa (pseudonym) cut 12 pentagons from the clay slabs. She used a bevel tool made from wood and wire (see Figure 9) to bevel the edges of the pentagons to approximately 30 degrees. Teresa joined the bevelled clay slab edges with a slip and scoring technique, where liquid clay is used as a 'glue' into scored clay as the two edges are joined. She added thin coils of clay and pressed them between two bevelled sides to provide additional support for the joints. After a first attempt at a dodecahedron, Teresa decided to start anew because she was dissatisfied with its asymmetries. She built the new dodecahedron from the base upwards and used a hair dryer to decrease the plasticity of the pentagonal sides as needed. She obtained the piece shown in Figure 6.

FIGURE 9. Tool for bevelling the edges of a slab of clay.

Given that sets of inexpensive plastic pentagons can be purchased and attached together in less than a minute, what is the idea of spending more than two hours making a clay dodecahedron? This is not something that we would address through controlled experiments but by attending to these hours of active hands engaged with tools in the course of shaping and being shaped by clay, by asking Teresa about the sense of pride and care emanating from the dodecahedron, or about her perception of the differences between the first and second dodecahedra, puzzled by the fact that both of them were 'imperfect', but the first was more imperfect than the second. Two hours of workmanship of risk and workmanship of problem-solving led to the creation of a dodecahedron that stands on its own, but in a deep and intimate relationship with the maker. Imagine the significance of placing the last pentagon on top of the 11 others, sealing an interior space that becomes an inscrutable region preserving countless traces and lived secrets that only Teresa might recall. This was only the beginning because, from then on, this dodecahedron began its life-as-a-thing.

Annie Albers, the great artist weaver, wondered why we would want to use manual looms at a time in which computer-controlled looms could greatly speed up weaving. Why go slow? These were some of her thoughts about it:

> [The] ability to form materials presupposes responsiveness towards the material, a flexibility of reaction, and this flexibility is one of the factors we will need for times to come. Through working with material, we can perhaps develop this ability to respond. More than intangible material, than tones or words, tangible material can teach that it has demands of its own and suggestions of its own for its forming, that it asks for a reaction. Creating means this reacting to material rather than the execution of a dream, as the layman conceives it. The first vision of something to be done gives more the mood of the work than its final form. The form emerges as the work progresses. (Albers, 1941, p. 3)

The foregoing is not a call to eradicate computer-controlled looms or plastic pentagonal faces. Instead, it speaks about the importance of fostering, perhaps occasionally, precious times placing our bodies in contact with primal sources, to encounter the needs and initiatives of materiality, which may be, among other realisations, irreplaceable springs towards becoming acquainted with the inner and vast lives of geometrical things.

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