EXPERIMENTAL ARCHAEOLOGY

A Perspective for the Future

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The Reuvens Lecture 5, Stichting voor de Nederlandse Archeologie, 1994.

Some thirty years ago experimental archaeology was generally regarded or rather disregarded as some strange pursuit entirely divorced from real archaeology: the excavation of sites, the processing of finds, the creation of typologies, and the understanding of the past. It was carried out by strange people who by some odd process of osmosis claimed to understand the past of whatever period. Re-enactment societies from Celts to Cavaliers made history come alive. Hunter-gatherers ravished remote landscapes in search of food for free. House builders cobbled together crude huts to experience the challenge and lived therein to prove their ability to survive. Roundheads fought Cavaliers in pitched battles to the thunder of cannons. Academia writhed in embarrassment and spurned these individual and collective nonsenses. The detail, the discipline and the data were sadly lacking. This, they said, was theatre. Rather than add to the sum of knowledge it fulfilled some inadequacy in the participants.

Unfortunately this attitude denied a great number of extremely respectable experiments (many carried out by eminent academicians) from the beginning of archaeology as a discipline. It seems a perfectly logical extension to the process of digging up objects and sites to ask how things actually worked and what they might mean. A brilliant survey of the early experimentation in archaeology has already been written by John Coles (1973).

The general view, however, has been gradually changed principally by two major research programmes: the Experimental Centre at Lejre in Denmark and the Butser Ancient Farm in England. The former created by Hans-Ole Hansen continued the great Scandinavian tradition of reconstructing and conserving past buildings by focusing upon houses; their reconstruction was based upon outstanding excavation plans and the study of their degradation through time even included their destruction by fire. Primarily, the intent was to elucidate the archaeological data. Significantly, education became the core motive if only to secure a financial base. The Butser Ancient Farm in England, begun in 1972, had a slightly different remit. It was set up as a project for research and education, its aim to study the agricultural and domestic economy of the late Iron Age and early Roman period in Britain. The concept was that the research itself would provide the educational material. The design included the construction of a working farm dating to c.300BC with livestock and plantstock to be complemented in time by a working Roman villa similarly fitted with all the accoutrements. As the invited director of this enterprise from its inception as a concept, its realisation forced the creation of a philosophy and a strict methodology.

The broad philosophy demanded that experiments should be conceived out of the archaeological data, and thereafter be driven by the scientific discipline specifically involved. Should an experiment be agricultural, it should satisfy an agricultural scientist; if a building, it should satisfy a structural engineer; if a programme of food conservation, it should satisfy a microbiologist. In addition, the human element should be removed as far as possible from any equation. The premise that our only escape is into the future was firmly embraced. It is impossible for modern man with all the impedimenta of modern technology to go back in time. The classic media question of "How does it feel?" is quite unanswerable. The objective was to explore the outstanding questions raised by archaeologists from their excavations, to attempt to provide real answers which could be substantiated again and again. Consequently, although it was to be a working farm, by definition this would be impossible. It would have the outward appearance of a farm but would be, in fact, an open-air laboratory where a series of integrated experiments would be in train.

The methodology inevitably was more difficult to determine, since its product (in contrast to the theories of philosophy based upon argument and reasoning) would have physical substance. Not only that but the substance must be repeatable not just by the originator but by others. The methodology had to be scientific in the sense that it fulfilled the basic scientific criteria. Interestingly this, almost from the outset, rather divorced it not so much from archaeology but from archaeologists. In fact, the methodology adopted is directly based upon experimental physics. The principles involved are relatively straightforward; a set of data engenders an hypothesis which is then subjected to empirical replicative testing with the primary purpose of destroying the hypothesis. If the testing fails to destroy the hypothesis, then it can be accepted as valid. Validity is a critical concept rather than truth since new data might emerge which could change the basis of the hypothesis. The significance of the methodology is that it is negative in its approach. The selection of data is determined as non-partial. It is not an adversarial argument in the sense of choosing only those data which fit the argument.

Thus for archaeological experiment one begins by not forming the hypothesis but accepting that of someone else. The normal pattern in archaeology is to conduct an excavation and then interpret the evidence recovered whatever it may be. Rather than use the term interpretation, one substitutes hypothesis for two reasons. The first allows it to fit into the formula adopted; the second allows it to be wrong. Unfortunately, the word interpretation today carries with it a degree of certainty or implicit rightness. Since the whole objective is to examine the interpretation for accuracy or rather inaccuracy, it is better to use a less deterministic word. Given the hypothesis, the experiment is designed to recreate it at a 1:1 scale based entirely upon the archaeological data. In this context it is most important to use the best data available. There is little or no point in having to create data in order to substantiate the hypothesis. The experiment itself is conducted within the confines of its scientific nature, and at the end of its process the data yield is directly compared to the original data. If there is a similarity, the hypothesis can be tentatively accepted as valid. If there is no similarity, the hypothesis can be rejected not just as invalid but actually wrong. The positive result of experiment over the years has ironically most frequently been negative. The methodology, in fact, is circular in form: prime data to hypothesis to replicated experiment to experimental data to prime data. By focusing in so much detail on the data themselves (often in greater detail than the excavator has the opportunity to do) and the ensuing hypothesis, should the final comparison prove negative an alternative hypothesis has often emerged. This in turn can then be subjected to the experimental cycle. An example of this, the so-called Romano-British grain drier, is discussed below. Again, even when an hypothesis has been confirmed as valid, it is not necessarily an exclusive statement since more than one hypothesis can be raised on the same set of prime data. As a case in point, the four-post structure found so frequently on prehistoric sites everywhere is capable of many perfectly reasonable explanations. This quite logically adds a rider to the formula in that there can be a multiplicity of hypothesis validation. The choice of which validation to use, therefore, depends on other data within the excavation.

From the very nature of the methodology it can be seen that experiment is very much restricted to the primary levels of the data. The results clearly have major implications in the structuring of overall theories and explanations, but the process is limited to the basic data.

Subsequently, experiment has been divided into five distinct categories. These are respectively construct, process and function, simulation, probability trials and technological innovation. Each category is discussed in turn below with examples to demonstrate how experiment has been pioneered.

1. Construct

The construct is perhaps the simplest type of experiment to explain, not least because it has the greatest visual and physical impact. The term construct is used purposefully to differentiate an experimental building from a reconstruction. The latter are those buildings which have sufficient material evidence to allow their accurate reconstruction. The obvious examples are to be found in open-air museums devoted to the preservation and conservation of buildings from earlier historical periods. These structures have survived to the time of their rescue often much altered but with enough of the original to allow the structure to be built as a representative of a specific period. Buildings from prehistory, on the other hand, are usually patterns of post and stake holes and often very little else. Creating a superstructure based on this kind of data can be an expression of artistic licence or pure imagination. However, it is still reasonable to make a case for such buildings in that they provide a target for criticism, and focus the attention of excavators to explain why such a structure is right or wrong. At the very least it provides an idea of space contained by a building (what appears as a small building in two dimensions as excavated is surprisingly large in three), and the material requirements for the building itself. These regularly defy the imagination in terms of the trees necessary even to build quite a modest structure.

Given the remit of the Ancient Farm to study the domestic economy of the late Iron Age in Britain, considerable attention has been paid to the buildings, their construction and function. The major difference between Britain and the Continent actually lies in the form of the buildings. In Britain the traditional houses are round in contrast to the Continental long houses. It is not unlikely that the difference can be attributed to function in that the long house normally has the provision of a byre for livestock at one end of the building with human occupation at the other, whereas the roundhouses seem to have no such provision at all. The difference in climate between the Continent and Britain is such that it is perfectly possible to keep livestock out in the landscape throughout the year in Britain. As Caesar observed, the frosts are less severe (*remissioribus frigoribus*), and certainly the snowfall hardly bares comparison. Whatever the reason for the roundhouse tradition, the typical domestic structure is in this form. Over the last thirty years this writer has built nearly all the variants of roundhouses as evidenced by the archaeological data. In broad terms, they fall into three sizes: small at 4-5m in diameter, medium at 6-9m, and extremely large at greater than 11m in diameter. Building materials vary according to landscape, with stone built houses in upland zones and timber built houses elsewhere. Construction type, too, varies from simple single stake walls to complex large double ring houses. For the purposes of this paper one particular example has been chosen to demonstrate the value of this type of experiment.

At the outset in the building of any construct the objective is quite specific. It is to examine in minute detail a particular structure by building it at a 1:1 scale, based entirely upon the archaeological data as revealed by excavation. It is, therefore, site specific. Ideally it should be done with the direct co-operation of the excavator with full access to all field notes and archive. In this way it is possible to focus upon the data precisely, and (given the constraints of creating a building) to isolate information within the data recorded but not recognised as significant. In simple terms it is a cyclical process involving direct feedback to the excavator, not only to enhance the understanding of this specific excavation but also to emphasise potential data for future excavations. This was exactly the case over the Pimperne House construct.

The house in question was excavated at Pimperne Down in Dorset in southern England in the 1960s, and provided remarkable detail of two double-ring houses, one built immediately after the other on the same location. It was possible to extricate the two ground plans more or less exactly. The minor confusion lay in the outer porch posts where the same postholes served both structures. The overall diameter of the house selected for the construct was 12.90m, with the outer ring comprising stakeholes and the inner ring (set 1.50m within) comprising standard postholes. These had clear postpipes indicating the original posts were averaging 0.30m in diameter. The porch protruded some 1.50m from the building and was 3.00m wide. The outer pair of postholes of the porch was much disturbed in contrast to all the others, the reason for which was not understood. Similarly, beyond the wall perimeter were a number of curving slots set 1.50m out. One initial thought had been that it might have been a triple ring house but little confidence was placed in this explanation. In the construct it was possible to begin with only one specific estimation, that of the wall height. This was determined to be 1.50m for no other reason than within the structure it would allow a person of average height to stand upright 0.30m from the wall. The guess (for that is what it was) proved to be inspired. The outer wall from the disposition of the stakes argued for a wattle construction thus making a powerful basketwork wall. Because it was determined that the roof had been thatched, the angle of the roof pitch is determined at 45-50^{o} for it to be waterproof, whatever the thatching material might be. Of the three obvious choices of wheat straw, river reed or heather (ling), the first was chosen as the most likely, given the location of the original site. With a roof pitch of 45^{o} and an outer wall of 1.50m, the inner ring of posts set 1.50m within needed to be 3m high. Since the fundamental form of a roundhouse is a cone set upon a cylinder, the inner ring of posts are tied together with horizontal timbers morticed and tenoned into place. Thereafter comes the major problem of the roof construction. Each rafter was a full-grown tree, and there was no way in which three could be tied together at the apex and raised into place as a tripod. Consequently, each principle rafter was pre-jointed to sit on the outer wall (allowing an eave projection to protect the daub on the wattlework), and be pegged on to the inner ring. The length of the rafters was simple to calculate; omitted from the planning was the weight distribution which was discovered empirically. The distance from the outer wall to the inner ring was a third of the distance from the outer wall to the apex of the cone which, when expressed in weight distribution, meant the first rafter offered into position promptly fell into the centre of the building. The re-appraisal of the original data which this forced virtually justified the whole undertaking. By extending the line of the rafter to the ground at the 45^{o} pitch, the rafter butt coincided exactly with the mysterious curving slots in the excavation. Analysis showed there were six such slots for each of the two plans suggesting a total of six principal rafters for the roof. The meaning of the curving nature of the slots emerged once the six rafters were in position. It is critical that the apex of the cone is exactly over the centre of the house otherwise it will exert disproportionate pressure on the walls. Actually moving the principal rafters into position (bearing in mind that each weighed several hundred kilos) was achieved quite simply by easing the butts of the rafters so that the ends of the rafters coincided at the apex over the centre of the building. The end product was almost an exact replication of the curving slots on the original. This finding achieved two things; first, it explained the curving slots and fixed the number of principal rafters, and second, it determined that the wall height previously guessed at was in, fact, accurate. The evidence was in the archaeological data but had not been recognised.

Given the six principal rafters, it was discovered that once in position these immediately began to sag under their own weight. Although attached to each other at the apex, each rafter bowed down creating a series of angles which did not correspond to the waterproof angle of 45^{o}. In order to obviate this effect it was necessary to insert a cross-braced ring beam one-third down the length of the rafters. This literally forced the rafters apart rather than held them together. Without this device it would be impossible to construct a successful roof. Only the empirical approach is able to isolate such elements: a *sine qua re non* or `without which thing then nothing'. The rest of the structure proceeded without major difficulty or discovery. All supplementary rafters were positioned and tied together with concentric circles of hazel rods, thus converting the component elements into an integrated cone. At this point all the weight thrust of the roof was vertically expressed and the building was perfectly stable. Finally, the roof was clad with a long-straw thatch, the walls were plastered with daub inside and out, and doors were fitted on to the porch. The sheer quantity of materials required for the structure was remarkable. Over 200 mature trees, mostly oak, averaging 0.30m at the butt, some 10 tonnes of clay to make the daub, and 12 tonnes of thatching straw to cover the roof. From the cereal research programme discussed below, the straw alone would be the yield from over 4 hectares. The roof weighed in all some 20 tonnes over a free span of 10m. The floor area measured in excess of 135sq.m. It was an extremely large and sophisticated building. Hardly could it be described in the traditional manner of a hut. The implications of this building in terms of economic and social status need not be of concern in this context, but they are considerable and enhanced simply because the building had been actually created in three dimensions. For the experiment this represented only the first phase. It is too easy to build a structure and forget that its real import lies in its durability through time. In addition several archaeological problems remained.

After the building was completed a number of observation experiments were set in train. The first of these was the decision to leave the butts of the principal rafters in position on the ground surface in order to see how long the wood would survive before rotting away. Prior to this the ground had been dug away from around each butt to demonstrate that they were no longer load bearing and that all the weight thrust of the roof was on the inner ring of timbers. Unfortunately, the net effect of this exercise has been to persuade people that these rafters reaching to the ground outside the building are necessary to hold up the roof and many representations have been published perpetuating this myth. A similar structure built by the author at the National Museum of Wales at St Fagans had these rafters cut off at the eaves to underline the point. The butts of the Pimperne House rotted away over a period of some 6 years.

A further observation programme was devoted to the wear pattern on the floor within the house, and the changes in the magnetic susceptibility of the earth floor itself. Otherwise it was a programme of monitoring the need for maintenance and repair.

During its life the structure was exposed to many climatic extremes including snow cover of some 0.40m (which effectively doubled the weight of the roof), many gales and storm force winds including the celebrated storm of 1987 which devastated this part of southern England. All of these extremes were sustained with little or no damage. In fact, the only major repair which proved necessary occurred after 8 years. The porch posts rotted at ground level, the zone most subjected to wetting and drying, and therefore microbe attack. In a sense this was one of the outstanding remaining questions, because in the original excavation these postholes were severely disturbed as indeed they are in a large number of excavated examples. The replacement of these two posts did not prove to be difficult. The porch lintel was raised from the tenons of the porch posts using opposing wedges. The posts were removed, but the stumps of the posts had to be levered out of the ground. This leverage process damaged the upper part of the posthole in a most distinctive way and which is mirrored in the archaeological postholes. Similarly, because the clearance between the lintel and the new posts' tenons was not great, a certain amount of manoeuvring had to take place to put in the new posts which further disturbed the postholes. The whole replacement exercise adequately explained why these postholes were radically different to all the others, which were, by the very nature of the building, protected from the weather.

With regard to the interior which was used for educational purposes as well as a visitor resource, three results emerged over a 15-year period. First, the wear pattern was disproportionate; the central zone of the house (the main floor area within the inner ring of posts) was considerably more eroded than the floor between the inner ring and outer wall with the floor area reduced overall by some 10cms. Secondly, the majority of activities took place in the southeastern half of the house, the porch being oriented to the southeast. Here were the greater majority of broken artefacts and objects. This finding has recently been confirmed by two excavations where artefact distribution was concentrated in this sector of buildings. Thirdly, the magnetic susceptibility of the soil within the floor area was considerably enhanced. This was undoubtedly due to the regular use of a centrally placed hearth. On average a fire was in use in the house some 200 days a year over 15 years. This enhancement was naturally restricted by the walls. This particular finding is important in the sense that it is perfectly possible to build such a house as this with only earth-fast postholes, and subsequently the only evidence of its presence could be a defined zone of magnetic susceptibility enhancement along with a distribution of artefacts. In fact, in this structure only an arc of postholes actually penetrated the underlying chalk rock.

This construct was built in 1976. In 1990 the Ancient Farm was required by Hampshire County Council to vacate the land it had used since 1972. In consequence, the sites had to be cleared. It was decided that this forced abandonment should be used to some end. One smaller house was burned down as an experiment, but it was decided to dismantle the Pimperne House in order to examine the kind of evidence it would leave. The thatch was stripped off the roof and the rafters carefully taken for potential re-use on the new site of the Ancient Farm. All the ties were found to be in perfect order and the roof was as strong as the day it was built. The inner ring was removed from the posts, at which point a startling discovery was made. Each of the upright posts had rotted away, one or two completely, the remainder partially inside their postholes. In the majority of cases the pith wood had rotted leaving the bark maintaining the postpipe in place and a cavity between it and the heartwood which differentially survived. In the cases of total loss of the post stump, the posthole was gradually filling with debris from the house floor. In the other cases, some material had found its way into the cavities including one hairgrip, two coins, a Coke can ring-pull, several sherds of pottery, and a button. From the normal monitoring it was known that the post stumps were deteriorating but not to the extent which proved to be. The logical deduction from this finding is both dramatic and disturbing. This construct of a great roundhouse is the first of its kind to have been built for two millenia. In effect, it is a reinvention but without the building knowledge and tradition of some two thousand years. These findings of the experiment are the result of natural processes hidden from the perpetrator, and therefore unmodified by him but are the results of processes which inevitably happened in the remote past. Given traditional knowledge, the answer to this problem is simply to fill up the cavities in the postholes as they occur. Ascertaining their presence is as easy as sticking a knife into the top of the posthole. Filling in the cavities is equally simple and ironically would lead to a post-hole in which the post-pipe is clearly defined and a series of layers within it mirroring the disappearing post stump - a not untypical representation of what is normally found. Further, the odd sherd or brooch or broken pin could find its way therein, especially when one considers the role of small children with even smaller fingers. As far as the structure is concerned it is perfectly sound and were it physically possible it would be advantageous to build it with the posts on the ground surface or even on stone pads. It is held in place by its weight and form; the posthole is only necessary during the building. However, if the above is further considered it means that a building like this can easily post-date the contents of its post-holes. Given the probability that most of these great roundhouses had a life span well in excess of two centuries, artefact remains from post-holes really cannot be used any longer as secure dating objects.

Finally, the removal of the outer wall revealed that a gully had been formed beneath the confines of the daub by rodents. Often this gully passed beneath the ends of the stakes which form the uprights of the wall, removing completely evidence of their presence. In an excavation, this house would have been described as having an encircling gully around it, perhaps indicating the position of an eave above it and the management of rainwater. In this connection what actually occurred directly beneath the eaves of the roof of this house and all the others the author has been responsible for is exactly the opposite. Because the ground immediately below the eave is protected by it, a special niche is formed where the plants flourish. So much so that at least once a year they have to be cut down before they reach the level of the thatch itself. The end result through time is a humic ridge. This even obtains if the eave space is used for storing wood for the fire.

From this construct it can be seen that the learning experience during the construction phase was perhaps at its greatest; however the life of the building over a span of 15 years provided even more significant findings all in terms of the improved understanding of the archaeological data and the paradigms it offers for subsequent excavations. Unless this is the purpose behind the building of a construct there is little to be gained.

2. Process & Function

The second category of experiment is described as process and function. This naturally enough involves the examination of how things actually work. This kind of experiment embraces trials with ards, how they stir the soil on the one hand, on the other the effect of the soil on the ard itself, the manufacture of tools like the vallus and the testing of its efficiency or otherwise in harvesting the prehistoric cereals, even the building of kilns and their use in firing pottery. All these experiments seek to elucidate the archaeological data. Within this category a large number of experiments have been carried out at the Ancient Farm including the examination of the Romano-British grain drier. These features are peculiar to the Roman period in Britain, and comprise an underground flue usually in a T-shaped plan with a drying floor placed above and enclosed by a building. A covered building is critical in the British climate. One such was built repeating exactly the excavated data and carrying out to the letter the accepted interpretation for these structures. However, repeated trials failed to dry grain at all. In the process, it was observed that two particular temperatures were easily achieved and maintained in the structure, one low the other high - exactly what was required for the malting of barley in the production of beer. This alternative hypothesis was extensively tested with a rewarding outcome described by the London Assay Office as a classic malt. This experiment demonstrates how the testing of one hypothesis which is found to be wrong led to a second hypothesis which was validated. Clearly other hypotheses could be raised for such a structure once the prime interpretation had been rejected.

But of all the process and function experiments that have been carried out at the farm, perhaps the most celebrated and significant have been those dealing with underground grain storage silos.

The science of storing grain in an underground silo or pit is relatively straightforward. Grain when placed in a sealed container like a pit continues its respiration cycle using up oxygen and giving off carbon dioxide. Within a short period the atmosphere becomes dominated by carbon dioxide at which point the grain enters a state of unstable dormancy. The instability is caused by the presence of micro-organisms, fungi and bacteria, which can survive in a carbon dioxide atmosphere. These micro-organisms are present on the grain in the field and are, therefore, introduced into the storage system along with the grain. Generally the pit itself is innocent of damaging micro-organisms. Their life cycle in the pit is arrested provided the temperature remains below 14^{o}C. In the case of a pit, this is normal since the temperature of the greater mass, the surrounding rock or soil, directly affects the temperature of the lesser mass, the grain stored in the pit. The greatest problem concerning grain storage within a pit is the possible admission of water or increased humidity from the surrounding material. If this occurs the respiration cycle of the grain is restarted with inevitable heating and the production of ideal conditions for the acceleration of the activities of fungi and bacteria.

When a pit is filled with grain and sealed, the seal itself needs to be an hermetic or waterproof seal against normal precipitation. The two natural hermetic sealing agents are clay and dung. Both depend upon being moist to remain waterproof. It is virtually impossible to protect the grain from all contact with the seal. In practice, the contact actually enhances the germination of the seed at this point (the upper part of the pit), and increases the rate of production of carbon dioxide. This gas, which is heavier than the intergranular atmosphere, sinks down into the pit and inhibits further germination in the grain mass. In fact, some immediate post-storage contact is both desirable and beneficial to the long-term storage success. Similarly, any humidity in the pit wall is exploited by the grain in order to germinate, which leads to further increases of carbon dioxide and to some drying of the pit wall. The major seeming drawback of storing grain in a natural pit, especially if outdoors, is that it is virtually impossible to remove a quantity of grain and reseal the pit. By its very nature the loss rate is increased because of the resealing process and the potential for water penetration is enhanced.

It is important to stress the difference between a sealed pit and a dry storage unit totally protected from the elements within a building like, for example, a pottery storage jar or pithos sunk into the ground within a storeroom.

The problem of water penetration into a storage pit is clearly demonstrated by the rock types into which they are traditionally dug. Almost without exception these rock types allow the vertical movement of water through their mass. Thus the typical rocks in which storage pits of all periods may be found are limestone, chalk, sand, sand and gravel and loess. A storage pit is never to be found in a clay because it is impermeable and allows only horizontal movement of water. Granite similarly is avoided.

There is very little documentary evidence for the practice of storing grain in underground silos bearing in mind their archaeological frequency in all periods. Two classical authors refer to it; Tacitus in describing the German practice of hollowing out underground caves which they cover with heaps of dung and use as storehouses for their produce (Germania, 16) and Pliny (Natural History) who describes the storage of grain in Spain. In the case of Tacitus it is extremely unlikely that he is quoting from his own observations so crude is his allusion.

Some 25 years ago, especially in England, there was considerable doubt expressed whether the large pits typically found on Iron Age sites could, in fact, have been for the long-term storage of grain. The argument against them stressed the intense humidity of the climate and, therefore, of the terrain so that any attempt to fill such a pit would be doomed to disaster. This argument gained support because the pits were peculiarly found only in Bronze Age and Iron Age contexts and not at all in subsequent periods. However, a series of empirical trials were carried out by the author and others on a number of different rock types including chalk, limestone, sand, clay and loess with quite remarkable results. It was perfectly feasible to store grain in this way in England. In fact, the author has stored grain in underground silos cut into chalk rock at Butser Ancient Farm in central southern England for a consecutive period of 18 years from 1972 to 1989. In addition, a series of pits were used for the experimental storage of grain at the Max Planct Institute near Cologne in Germany also under the aegis of the author. Indeed within the last year grain has been stored in an underground silo in the site of L'Esquerda, a mediaeval settlement in the Plana de Vic, Catalonia, Spain with complete success. All the experiments proved beyond doubt the efficacy of the system described above and more importantly demonstrated that grain stored in this way retained an extremely high level of germinability despite being in an atmosphere of up to 20% carbon dioxide by volume for over a six month period. The average loss rate from the storage system is some 2-4% of the stored bulk of grain, but the loss rate is properly a function of the ratio of wall area to volume. One further major result from the experimental trials was the innocence of the pit as a container. The same pit can be used over and over again without any deleterious effect upon the grain whatsoever. In other words, a pit does not become unusable because of a build up of micro-organisms making it foul; a pit, therefore, has an unlimited life-span. Consequently, it is impossible to create a spurious formula of pit capacity against annual consumption per capita to arrive at a population figure. These experiments also examined different types of lining for which there was putative archaeological evidence. A basketry lined pit proved unusable after the first year since the wood became an ideal substrate for concentrating micro-organisms. On the other hand, a clay lined pit worked extremely well for many years. The clay simply acted as a barrier against any further penetration of water although its own humidity accelerated germination of the grain and slightly increased the loss rate.

The supposition that these pits of the British Iron Age were most probably for the long-term storage of grain was further substantiated by two results of the experimental work. Most of the pits of the long-term experiments were completely unlined, the grain being simply poured into the pit and sealed completely with a clay capping covered with soil. In consequence the grain next to the wall and the seal germinated, putting out shoots and rootlets. As the carbon dioxide gas concentration increased within the pit, so these germinated grains died forming a skin approximately 20mm thick against the wall of the pit. Once the storage period was over and the good grain removed, the skin remained firmly adhering to the pit wall. To clean the pit prior to further storage this skin was normally removed by pulling it away from the wall surface. This process actually removed small particles of chalk from the pit wall which had become entangled with the seed rootlets. After several years use the result was a completely smooth pit wall in contrast to a recently dug pit where the walls were quite rough. A large number of pits from Iron Age sites show exactly similar smoothing of the pit walls. The second substantion also arose from the grain skin which forms against the pit wall. An alternative method of removing it by fire was tried on several occasions. Two methods were used. The first was simply to have a fire in the base of the pit and keep adding fuel in the form of brushwood and straw until the skin had been burned away. The second was to remove the skin first by dropping it into the bottom of the pit and then burning it *in situ*. The results of both methods were extremely similar in that once the fire was finished a quantity of carbonised grain survived in the bottom of the pit. Close examination of this seed showed that a high proportion had lost the germ element of the seed. Analysis of carbonised seed from a grain storage pit at Danebury Hill Fort in Hampshire, England demonstrated exactly the same result. A proportion of the carbonised seed had lost the germ element. Although not impossible, it is very difficult to think of alternative reasons for either the smoothing of a pit wall or the survival of carbonised seed missing the seed element. Finally, this last observation underlines that viable seed was stored in the pits, not seed which had been previously parched or roasted to reduce its moisture content.

This cycle of experiments in particular demonstrates the methodology of experimentation and the need for extensive replication.

3. Simulation Trial

The third category of experiment is the simulation trial. By definition this type of trial, in order to provide a practical paradigm, requires the creation of a new state of the hypothesised original. The most apposite example of this is the experimental earthwork and the most remarkable exemplar is the experimental earthworks of Overton and Wareham Downs. In 1962, a new departure was initiated in experimental archaeology with the construction of a monumental earthwork at Overton Down in Wiltshire. This was a product of a group of leading archaeologists in Britain who were interested in the processes of construction, but more particularly what happened to such an earthwork through the passage of time and, further, what happened to materials buried in the bank of the earthwork. It was also the first time that an extremely long-term experiment had been designed in that it would outlive its progenitors by some considerable time. The proposal was that the ditch and bank would be regularly sectioned after 1 year, then 2 years, then 4 years, and then thereafter on a binomial progression until 120 years had passed. Currently the 32-year examination has just been completed and is scheduled for publication in 1995. This earthwork was constructed on upper chalk on the open downs. In 1963, a second earthwork of exactly similar proportions and design was built on the sands at Wareham Down which has received the same treatment throughout. Both earthworks are linear and specifically they simulate prehistoric territorial boundaries where the bank was set at some distance from the ditch creating two elements rather than an integrated unit. However, with the advances made in scientific archaeology over the last decade especially with regard to soil sciences, these earthworks are providing a wealth of invaluable data to enhance the understanding of the archaeological evidence from actual sites.

In 1976 another experimental earthwork was created by the writer with a totally different purpose. The object was to simulate the typical ditch and bank which surrounded small settlements of the Bronze Age and Iron Age in order to examine the erosion patterns in so far as they create specific layers in the ditch profile when excavated. In this case the ditch and bank were integrated together so that they formed an entity. In effect it proved to be a pilot scheme. The ditch and bank formed an enclosure which was the focus of the museum area of the Butser Ancient Farm. Rectangular in plan it was based upon an actual Iron Age earthwork at East Castle in Dorset. The ditch was dug with V-section 1.50m deep and 1.50m across the top. A space was left between the edge of the ditch and the bank of 0.30m. This is technically described as a berm. The turf which formed the surface of the ditch was carefully cut into sods which were made into a low retaining wall set at this point from the ditch edge. The material from the ditch was made into a dump bank; thus the material from the depths of the ditch formed the uppermost covering of the bank. The ditch was cut into middle chalk. Finally a wattle fence was built on top of the bank.

From 1976 to 1984 the earthwork was monitored and every effort was made to keep both animals, especially rabbits which did not appear in Britain until the tenth century AD, and people out of the ditch. Inevitably this failed, normally in the case of small boys who happily are heedless of rules and regulations. No doubt the modern version apes his prehistoric ancestors. The interference was minimal and certainly indiscernible. Because the Ancient Farm is equipped with a meteorological station, daily records are available for the full life of this earthwork. It was soon realised how critical the weather was in terms of simple erosion. However, what proved to be most remarkable was the speed at which vegetation began encroach. Since the ditch cuts through the topsoil, a face is left from which plants immediately begin to germinate. Similarly, the surface of the berm (which was grassland and despite the construction of the earthwork is largely undisturbed) becomes a reserved area in that neither people nor animals walk or graze there. In consequence the grass grows abundantly and in contrast to a meadow or paddock where the grass is cut or eaten it reaches maturity and seeds. These seeds fall *in situ* and germinate in due season. On the bare chalk faces of the ditch within a few short weeks mosses began to grow. These formed discrete catchment zones for particles of soil which tumbled from the soil profile and thus provided niches of nutrient for seeds to exploit. The effect of this vegetative activity was critical to the future of the earthwork. First, the uninhibited growth of plants on the berm provided a complete brake for particles of soil or chalk to fall from the bank into the ditch. In addition the growth of plants from the exposed face of the inner side of the ditch was unchecked and served to hold the soil in position. The reverse was the case for the outer face where animals grazed and people walked. Here the vegetation struggled to survive and erosion was ongoing. Within the space of two years the bank, raw chalk, was being colonised especially by arable weeds and wind blown ruderals. By 1982 the bank was totally stabilised by vegetation which had gone through a natural sequence of opportunistic plant occupation to a more stable plant community which even included several trees (*Sambucus nigra*) and bushes (*Corylus avellana*) as well as brambles (*Rubus fruticosus*) and dog roses (*Rosa canina*). The majority of the ditch was also stabilised except for the upper outer face where active erosion continued. In 1984 a series of sections were cut across the ditch on the east, south and north sides of the enclosure with totally unexpected results. While each section recorded a similar result which varied only in depth of deposit for each layer, the layers themselves were the `wrong' way round. It is normal to find on archaeological ditches that the layers are not evenly distributed in the sense that one side always seems to have a greater quantity of material than the other does. This has often been used to argue that the side with the greatest deposit is the side where the bank was located. The experimental ditch showed exactly the opposite. The reason is not difficult to isolate. The skewed deposition of material is caused directly by the pattern of vegetative growth on the inner elements of the ditch and bank.

In addition, since stabilisation had taken place so quickly the normal time-scale previously suggested had to be dramatically revised. There were a relatively large number of deposition layers even though the time-scale was so short. On average there were three distinct erosion events every year though some erosion was continuous. This was the dried surface material on the ditch faces, which is washed down each time it rains. These ephemeral episodes are virtually impossible to isolate.

The results from this pilot scheme led immediately to the implementation of a major experimental design. The pilot earthwork had been expressly simple in concept and had posed very few questions. While perfectly acceptable as a basic premise, indeed desirable in any experiment, it was decided to increase the scale to incorporate different designs of bank construction to test their significance in erosional terms into the ditches and to increase the exposure of the earthwork to all the points of the compass. Further, since the pilot earthwork had been on middle chalk, the least preferred geology by ancient and modern alike, other basic geologies should be tested.

The design adopted was an earthwork of octagonal plan with a length of ditch exposed at right angles to each major point of the compass. Each length of ditch at 20m was to be divided into two sections, one with a berm of 0.30m as before, the other to have no separating berm between the inside face of the ditch and the bank. Also each half should be divided into two sections of 5m, one half with the bank constructed with a retaining wall of sods or turves, the other half to use the sods as the core of the bank. In other words, the ditch surface would be dug up and the up-cast material would form the heart of the dump bank without any preparation. The first of these experimental octagonal earthworks was constructed on the lower chalk in the grounds of the National Science Museum Reserve Collection at Wroughton, near Swindon in 1985. A second was built on the Aeolian drift of the coastal plain of southern England in the grounds of Fishbourne Roman Palace, Chichester, Sussex in the same year. Finally, a third was built on the upper chalk at the new site of Butser Ancient Farm at Bascomb Copse, Chalton, Hampshire in 1992. Each one is accompanied by a meteorological station and each one is monitored annually to record the vegetation cover. As each reaches full maturity, currently estimated at 12 years, they will be subjected to physical examination including an archaeological section and allied soil science sampling.

Ultimately these experimental earthworks will provide a comprehensive set of comparative data for archaeologists working in the field. From the process of simulation, the paradigms provided are completely understood and fully recorded and where agreement is found in an original it can be more completely understood. Already sufficient data have been obtained from the pilot trials and the later vegetation surveys to make predictive analyses but strictly in accordance with like geologies and climatic zones. In an ideal world each geology and climatic zone occupied by prehistoric settlements with encircling domestic ditches and banks should have a reference experimental earthwork.

4. Probability Trial

The fourth category of experiment is the probability trial. This in a very real sense is a combination of the first three categories with the added component of seeking an outcome. The ideal example of this type of experiment is the long series of agricultural trials carried out at the Ancient Farm since 1972.

In practice the results from such trials have to be carefully defined in terms of the variables and constants within the experimental design which, in turn, is dictated by the question asked. For example, the cropping trials at the Ancient Farm set out with the simple question of what the yields might have been in the latter part of the first millennium BC. However, to produce an answer to such a question is extremely complicated. The ploughing technology of this time is well evidenced by iconography, the rock carvings from Scandinavia, France and Italy, and by the implements themselves. Manufacturing replica ards and ploughing with trained cattle form an essential component of the experiment in the sense of soil preparation. However, the effect of this type of cultivation is directly similar to hoe cultivation. Thereafter the situation becomes more complex. The type of cereals grown is attested by the evidence of carbonised seed and it is possible to obtain the same type of cereals today. But, in the case of Emmer wheat (*Triticum dicoccum*), for example, there are several different types of Emmer, each suited to different bioclimatic zones, although it is thought that all types survive within any assemblage to a greater or lesser extent. It seems reasonable to accept that the same situation was obtained in prehistory, but there is some uncertainty. The morphology of the seed is exactly similar, but its behaviour might differ. With regard to the soil, there is similar uncertainty; not so much of the types exploited and their presence today, but the effect of modern agrochemicals. In this respect, the soils used by the Ancient Farm were unaffected until the third location at Bascomb Copse. Logically, the modern chemicals used are either short-lived or become inert within the soil structure, and are unavailable for plant take-up. Interestingly, on the new site, where the land had been intensively farmed in the modern manner, once it had been taken over the arable weed flora which emerged during the first two years before cropping trials could seriously begin was absolutely remarkable. Several extremely rare arable weeds appeared in abundance, notably sharp-leaved fluellen (*Kicxia elantine*). The conclusion to be drawn is that modern farming has a minimal long-tern effect. The soil, nonetheless, itself changes depending upon treatment, the application or not of manure, the types of plants grown (whether nitrogen users or nitrogen fixers) along with the appropriate microbes, the manner of crop management with weeding or without. Most critical of all is the weather pattern. It is not an idle observation to record that each year is a unique climatic event. All these variables have to be of account. Indeed, given the number of variables it is vital that any cropping trial spans at least a decade in order that any conclusion drawn from statistical averages is influenced by as full a range of variables as possible.

Any agricultural trial is subject to the five basic criteria of farming: the climate, the soil, the crop or cereal type, the nature of treatment and, finally, pests and pestilence. Of these, the first is the most critical, without adequate rainfall and temperature ranges agriculture is not possible. The climate virtually dictates the general outcome. The soil in pre-agrochemical times similarly determines what plants may actually thrive and what will not. Thereafter, it is a matter of choice until the fifth category. These criteria were well known in the remote past and are splendidly exemplified by a poem written by a Greek poet, Agathias (AD536-82), about a peasant farmer called Kalligenes who consults an astrologer about the potential harvest he might achieve:

The astrologer cast his stones across the board
Studied them, wriggled his fingers and said;
"If, Kalligenes, there is rain enough
On enough of your land, and if the weeds
Don't take over, nor the frost wreck the lot,
If a hailstorm doesn't knock it all flat
If the deer don't nibble, if no calamity
Up from the earth or down from the sky
Occurs, the signs show a good harvest
Unless there's a plague of grasshoppers."

The probability trial, therefore, is extremely complex in terms of recording all the variables and presenting the results within the strict parameters of the experiment. In order that the results are acceptable not just to the archaeologist but to the agriculturist/agronomist it is also critical that the experimental design images modern agricultural research design and sampling technique. As a small example, when sampling a crop the area cultivated has to be large enough to completely ignore a metre wide perimeter band around the crop to avoid the edge effect. Anything less and the results are valueless.

It was in the context of all the above that the cropping experiments at the Ancient Farm were conceived and executed. The results from these experiments, fundamentally on a worst option scenario given an extremely poor soil and bioclimatic zone, have been quite remarkable. Across all variables over some 15 years, yields for Emmer wheat average without manuring some 1.5 tonnes per hectare, with manure 3.6 tonnes per hectare. Similar results have been obtained for Spelt wheat (*Triticum spelta*), Bere barley (*Hordeum vulgare*) and Einkorn (*Triticum monococcum*). Of much greater interest are the results from specific treatments: manured, or non-manured, spring or autumn sown, annual fallowing and crop rotation.

The value of this kind of experiment goes far beyond the simple statement of the yield figures however important they may be for assessing economies. In the creation of a field trial, one is producing the right conditions for the study of plant communities, and how those communities are affected by different treatments and processes like manuring which reduces soil pH and harvesting which only partially reflects plant presence from the field to the settlement. From such trials the carbonised seed assemblages can be assessed as to their relevance to reality or their acceptance as mere lists of presence or absence. Observations of the arable weed communities show that they vary considerably according to treatment and weather patterns. Similarly, such trials offer opportunities for pollen rain experiments. In fact, a series of these last have been carried out at the Ancient Farm with the surprising result that the cereal pollens travelled little more than 0.50m from the edge of the crop field. Typically, the experiment raised more questions than it answered.

In an ideal world this particular type of experiment should be in train throughout Europe and the countries of the Mediterranean basin. In this context the author already co-directs an agricultural research programme on exactly similar lines at L'Esquerda in Catalonia which is devoted to mediaeval studies.

5. Technological Innovation

The fifth category of experiment is best described as technological innovation. Within this category fall the initial application of machines or trials which seek to improve or enhance archaeological practice, whether excavation technique or prospection development. Particularly is this the case with prospection machines like fluxgate gradiometers and soil magnetic susceptibility meters, ground radar and even X-rays borrowed from other disciplines. The initial use of the well-known resistivity machine was an experiment, and its adoption as an archaeological tool only came after a series of trials. It is the same with all such machines. The examination and testing of these devices to assess their potential value are, in fact, experiments.

Similarly monitored field trials can be used to facilitate the understanding of recovered archaeological data. For example, in order to investigate the vexed question as to whether the topsoil should be regarded as an archaeological layer and the artefacts within it should be significant, the writer has carried out a long series of trials recording the movement of artificial sherds under both modern and prehistoric cultivation regimes. The results to date suggest that the average distance of an artefact from its original deposition point is barely a metre. This result allied with surveys by magnetic susceptibility meters whose penetration from the soil surface is some 10cm suggest strongly that the plough-zone fully deserves to be recognised as an archaeological layer, and should be granted the same attention as those layers arguably undisturbed by subsequent activity.

All these different categories and the examples quoted comprise the full nature of experimental archaeology. In effect, experiment is central to the practice of archaeology; it is the argument which allows progress and forces re-appraisal and change, which focuses upon anomalies and absurdities. Experiment is no more than the application of deductive logic reinforced by physical testing. Without experiment, archaeology would stagnate into endless repetition and unquestioned typologies. Interpretations, theories and hypotheses (it barely matters which term is employed) must be challenged, explored, tested before they become folkloric fact entrenched in accepted wisdom.

Conclusion

Experiment - but why a perspective for the future? If experiment by definition must be driven by the data, surely it has to be retrospective in the sense that it confirms or denies an hypothesis raised upon an excavation or series of excavations. The argument has been made that experiment is central to interpretation certainly of the base level data and, therefore, fundamental to interpretation as a whole. Experiment has increasingly brought scientific discipline to bear upon a subject steeped in a traditional arts thinking. The result has been uncomfortable and in many cases almost incomprehensible since the specialist (for which read scientific) reports are still consigned to the end of papers, their import barely recognised and their content rarely incorporated. Excavations are still driven by walls and mosaics, pottery and plans. The sheer plethora of this information largely underlines our lack of understanding of the why and the how. However, science has this fascinating diversion of the `what if' scenario. *What if* this building were used for stock? *What if* this soil was last ploughed by an ard? *What if* this pit was for animal or human waste? The second part of the question is: `what would the evidence be?' Here is the perspective for the future. Only experiment can provide the paradigm. Only experiment can yield the scientific model in the form of real data against which the material evidence from excavation can be compared. The great majority of this data will in all probability be invisible to the digger, the excavator in the field. It will be taken away in specimen bags for laboratory analysis, in sample tins for subsequent thin sectioning and microscopic examination, in sample bags for magnetic susceptibility testing. In particular, the advent of the soil scientist during the last decade has drastically altered the way in which archaeology is to be approached. But the soil scientist has and continues to discover more and more anomalies that, without deductive `what if' hypotheses followed by empirical trial to provide working examples, will remain anomalies. The future perspective lies in continuing the nature of integrated experiment as pioneered at the Ancient Farm to explore the agricultural and domestic economies in the macro state, and to incorporate within those experiments controlled micro state environments at the behest of and with designs from the specialist scientist.

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