The Ingenious Mr Padmore

Eighteenth-Century Polymath

By

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In *'A Tour thro' the whole island of Great Britain*[i]', published in 1742, Daniel Defoe describes the Great Crane of Bristol as being *'the workmanship of the late ingenious Mr Padmore'*. So, who was the ingenious Mr Padmore? In his will, Padmore describes himself as a millwright and shareholder in the Bristol Brass Company. Records show that he built copper smelting mills (1717), battery mills for the manufacture of copper hollow-ware and rolling mills for the production of sheet metal (1732). He also designed and constructed atmospheric engines for raising water (1695), he built a floating harbour at Sea Mills on the River Avon north-west of Bristol (1715), 90 years before the Bristol's Floating Harbour, he contributed to the construction of the Avon Navigation (1727), making the Avon navigable for trade between Bristol and Bath, he constructed Ralph Allen's tram-way for transporting stone from the mines at Combe Down to Dolemeads Wharf on the River Avon in Bath (1729), he constructed cranes for loading stone into barges at Dolemeads Wharf (1729) and he constricted the Great Crane in the Mud Dock in Bristol (1733). Today we would describe John Padmore as an engineer, we should therefore consider Padmore as an engineer in the age of enlightenment.

John Padmore of Bedminster and Barton Regis

John Padmore, millwright of Barton Regis, died in 1734, his will[ii] being proved on the 18th of September, witnessed by John Brice, William Hicks and W Hibbs. He left his five shares in the '*Brass Battery and Wire Company of Bristol, Esher, Upper Redbrook and Barton Regi*s' to Nehemiah Champion, a Bristol merchant and director of the Bristol Brass Company, Onesiphorus Tyndall, also a Bristol merchant and destined to become the senior partner of the Old Bank (the first bank to be established in Bristol) and Joseph Lamming of Barton Regis. The shares were left '*upon trust that the dividends and prophets be paid to [his wife Sarah Padmore nee Halbrow] so long as she shall live'*. Padmore also bequeathed £500 to each of his three daughters upon reaching the age of 21 (equivalent to £70,000 at 2015 prices).

The earliest reference we have to Padmore's work is in 1695[iii] when he is credited with the construction of a '*remarkable atmospheric engine*' at Conham to supply Bristol with water. Padmore died in 1734, indicating a working career of at least 40 years. A portrait of John Padmore exists [Figure 1], painted c.1734 shortly before his death. The portrait shows a man in his 30s, who is clearly too young to have been constructing atmospheric engines in the 1690s. Are we therefore looking at two people, a father and son; John Padmore the Elder and John Padmore the Younger?

Bedminster records reveal the birth of a son, Thomas (1690), and a daughter, Lydia (1691), to John and Elisabeth Padmore. But Thomas and Lydia did not survive childhood, Thomas dying in the same year as his birth and Lydia in 1693 at the age of 2. John Padmore next appears in the church records of St Augustine-the-Less in 1720 where he marries Sarah Holbrow. Is this John's second marriage at the age of around 50, Elisabeth having died, or is this John Padmore the Younger, son of John Padmore the Elder and Elisabeth, and sibling of Thomas and Lydia? Sarah is recorded as John's wife in his will of 1734, with whom he had three daughters; Elizabeth, Sarah and Mary. Circumstantial evidence supporting the theory of Padmore the Elder and Padmore the Younger could be the choice of the name Elizabeth for his eldest daughter, named after his mother? A third piece of evidence also exists in John Padmore's portrait. The painting, now in the collection of the Bath's Victoria Art Gallery, is possibly the painting listed in an auction catalogue of Ralph Allen's estate in 1769[iv]. As observed by Watts[v]: 'the man in the portrait would appear to be about 30 to 40 years of age', meaning that John Padmore was born around 1700 and died in 1734. In his will, John describes himself as '*being indisposed in body but of disposing mind and memory'*. This would imply that he was in poor health, which would accord with the gaunt image captured by Van Deist. If John Padmore were the father of Thomas and Lydia by his first marriage, and Elizabeth, Sarah and Mary by a second marriage, it would suggest a date of birth for John before 1670. This would make him around 70 at the time of his death in 1734. If John Padmore the younger were a sibling of Thomas and Lydia, he would have been around 35 at the time of his death. The balance of evidence suggests a John Padmore the Elder and a John Padmore the Younger and it is this premise that has been adopted in this paper.

Figure 1 John Padmore the Younger c.1734 by Johen van Diest (1695 to 1757)
[Courtesy of the Victoria Art Gallery, Bath]

Atmospheric Engines

Padmore the Elder's involvement with the pumping of water dates from the mid-1690s. There are records of at least two pumping engines being constructed for the Bristol Water Company in 1695, one at Conham[vi] and a second at Hanham[vii]. A third machine is recorded a year later (1696) at Hotwells where Shebbeare[viii] describes:

> *Mr Padmore, (a Man well known for his Genius in Mechanics) inclos'd it [a spring] within a Cistern, and affixed Pumps to the Spring, by means of these the Stream is elevated almost thirty feet.*

Bristol Water Company

The earlier pumps are recorded by Evans[ix] in the 'History of Bristol' [1824]:

> *(In 1695) a special Act of Parliament gave to a 'Bristol Water-Works Company' the right, title, and privilege, to serve and supply the inhabitants of Bristol with fresh water for two hundred years, upon payment of £166 13s 4d to the Chamber of Bristol every seventh year. A reservoir, still existing (in 1824) at Lawrence-Hill, was supplied from a place at Hanham called the Engine-Mill.*

Writing in 1820 Cooke[x] recalls the construction of hydraulic machine at Crews Hole and credits it to John Padmore:

> *About a mile and a half east of Bristol, on the banks of the river Avon, is a place called Crew's Hole. Here is a curious hydraulic machine, invented and constructed by the late ingenious Mr Padmore, for throwing water into a reservoir for the use of the city of Bristol.*

Evans and Cooke appear to draw on the earlier work of Samuel Rudder[xi], who in his 'History of Gloucestershire' [1779] described the water company at St George, then just outside the city of Bristol and within which parish lie Crews Hole and Conham:

> *Here are two copper-works and a glass-house for the manufacture of bottles. But the principal production of art is a curious hydraulic machine, erected upon the river Avon, and invented and constructed by the late ingenious mechanic and mathematician, Mr. John Padmore, for throwing water into a reservoir, for the use of the city of Bristol. The reservoir is at a little distance, on the top of a hill, whence, by subterraneous pipes, the water is conveyed to the city. There were formerly two machines for the same purpose, at Hanham-mills, in the parish of Bitton, but they were taken down in the year 1720.*

It is interesting that Rudder also identifies two copper-works. These are the copper smelting mills of John Coster at Crews Hole and Abraham Elton at Conham which were later to be subsumed into the Bristol Brass Company; in which John Padmore the Younger was a shareholder.

The Bristol Water Company obtained its supply of water from the Avon at Hanham Mills, which was pumped to Crews Hole by a hydraulic machine and then by a second machine to a reservoir Lawrence Hill. Evans continues that in 1697 the "new river water (was) brought into the city through elm-pipes from Hanham Mills". The company however failed, as observed by Evans:

> *Considering the number of more ancient conduits of water into the heart of the city, that even now (1824) bestow their original plenitude of supply, and the facility with which water is everywhere obtained by piercing to no great depth, it is not surprising that this speculation soon failed. The freehold and leasehold land near Bristol, and a small piece of leasehold land in the parish of Bitton, belonging to the Company, were sold by auction on the 27th of June 1811. The Bristol Dock Company purchased Hanham Mills, but not the right of supplying water.*

The company may have failed but Padmore's ingenious machine was a success.

Hotwells

Turning to Hotwells, Evans's entry for 1696 in the History of Bristol states:

> *The Hotwell-House erected, with the pump raising the water 30 feet, at the cost of Sir Thomas Day (mayor in 1694), Robert Yate (mayor in 1693), Thomas Callowhill, and other citizens; a lease having been granted for that purpose by the Society of Merchants, as lords of the manor, for ninety years, at £5 per annum.*

Shebbeare[xii], writing in 1740 in 'A New Analysis of Bristol Water' describes:

> *The Situation of the Hot-Well is as picturesque perhaps as can be imagin'd; it lies on the Side of the River Avon about a Mile and half distant from the City of Bristol. The Stream issues from a very high Clift of Lime Rock, perhaps two hundred Feet below the Summit, and ten above the Level of Low Water, but as the Water rises here in the lowest Tides thirty Feet, and in the Spring much more, it was of Necessity render'd inaccessible some hours every Day, till Mr Padmore, (a Man well known for his Genius in Mechanics) inclos'd*

it with a Cistern, and affixed Pumps to the Spring, by means of these the Stream is elevated almost thirty Feet in all its native Heat, Purity, and Perfection.

The dimension 'thirty feet' is significant being the maximum head of water that can be raised by atmospheric pressure.

Water Commanding Engine

So, what were the hydraulic machines designed and constructed by Padmore. The Annals of Bristol[xiii] give a further insight, describing the machine at Conham as a 'remarkable atmospheric engine', implying an early steam engine. Thomas Newcomen did not patent his atmospheric engine until 1705 and a working engine was not constructed until 1712; so Padmore's engines predate those machines by a decade or more. An alternative is that Padmore was employing a Savery engine. Thomas Savery [1615–1715] patented his steam engine in 1698, being:

A new invention for raising of water and occasioning motion to all sorts of mill work by the impellent force of fire, which will be of great use and advantage for drayning mines, serveing townes with water, and for the working of all sorts of mills where they have not the benefitt of water nor constant windes.

Savery demonstrated his engine to the Royal Society in 1699 and it was not until 1702 that a drawing of the machine was published in the 'Miners Friend'[xiv]. Padmore's machines therefore pre-date both Newcomen and Savery. So, was Padmore looking back to the work of the Marquis of Worcester (1603-1667) who published a design of a 'Water Commanding Engine' in 1663[xv]? It has been suggested that Savery based his engine on the Marquis of Worcester's Water Commanding Engine, and indeed there are many similarities between the two devices. The Water Commanding Engine is shown at Figure 2, and its operation of is described by Thurston[xvi]:

Steam is generated in the boiler D, and thence is led into the vessel A, already nearly filled with water. It drives the water in a jet out through a pipe, F or F'. The vessel A is then shut off from the boiler and again filled "by suction" after the steam has condensed through the pipe G, and the operation is repeated, the vessel B being used alternately with A.

A visitor to the Marquis of Worcester's Vauxhall workshop in 1663 described seeing the "hydraulic machine which the Marquis of Worcester has invented." It was designed for irrigation, and would "raise to the height of forty feet, by the strength of one man and in the space of one minute of time, four large buckets of water"

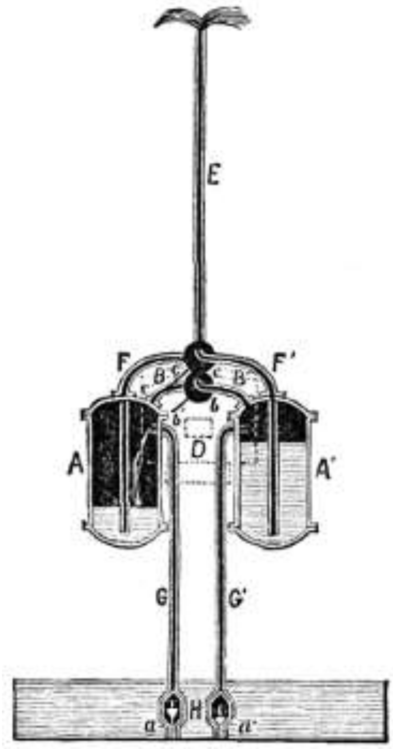

Figure 2 The Water Commanding Engine

Was Padmore using concepts put forward by the Marquis of Worcester for irrigation by means of a 'Water Commanding Engine' to provide a water supply for Bristol? Padmore's hydraulic machine could have raised water at Hanham Mills to an intermediate cistern from which it fell by gravity through elm pipes or an open leat to Crews Hole, where it was again raised by a second Water Commanding Engine to the reservoir at Lawrence Hill. A similar machine could also have been used at Hotwells to raise the spring water to a level well above the high-water level of the Avon.

Copper

Coincident with Padmore's work on the Atmospheric Engine at Crews Hole, the Merchant Venturer Abraham Elton (1654-1727) was developing a copper mill at near-by Conham. Elton's mill was established in 1696 for smelting copper ore shipped from Devon and Cornwall using coal mined locally in Kingswood, so leading us into the second chapter of our story.

Padmore the Younger's links with the copper and brass industry are self-evident through his holding of shares in the Bristol Brass Company and the leaving of those shares to Nehemiah Champion (1678–1747), a partner and innovator in the company which dominated the industry in the Avon Valley. Padmore the Elder also appears to have been connected with the industry from its earliest days and was certainly involved with an off-shoot of the Bristol industry in Swansea at its inception, which was to flourish in later years.

Bristol Copper

Bristol became an international centre for copper and brass production in the early 1700s, the origins of which go back to 1679 and a patent granted to Lord Grandison and a Mr Hutchison for a reverberatory furnace, being:

> *'a new invention to melt and refine lead ore in close or reverberatory furnaces with pitcoal sea coal or turf peat or other mixed fuel not mixed with wood… or charcoal'*[xvii]*.*

The reverberatory furnace enabled coal to be used for smelting metals which had formerly required the use of charcoal; which was becoming scarce and hence expensive. The reverberatory furnace was adaptable for smelting copper and reserves of coal existed in shallow workings in Kingswood. Copper ore was being raised from mines in Devon and Cornwall as a by-product of mining for tin but was being discarded as waste (referred to as poder[xviii]) as adequate supplies of fuel were unavailable locally for smelting; the smelting of copper requiring large quantities of fuel, at least four tons of coal being needed to smelt one ton of copper. Merchant Venturers such as Abraham Elton bought supplies of poder at relatively low prices and transported them by sea to St George, then just outside Bristol, where it was smelted using local Kingswood coal.

Nehemiah Champion was also active in St George in the early 1700s. Bristol Port records show him importing copper ore from Cornwall to Crews Hole in 1706 and in 1711 he establishing a copper works there under the control of John Coster of Redbrook. John Coster (1647-1718) had been operating a copper works at Upper Redbrook in the Wye Valley south of Monmouth but in 1711 moved his operations to the Avon valley [Day and Coverdale[xix]] and in 1722 the Redbrook Copper Works was assimilated into the Bristol Brass Company.

It was in the midst of these developments that Padmore became involved with a rival initiative in Swansea.

Llangyfelach, Swansea

The Bristol initiative was mirrored by a similar initiative across the Severn Estuary in Swansea. In his introduction to Copperopolis[xx], Hughes states that:

> *Swansea was the first industrialised region in Wales and its pre-eminence as the international centre of copper-smelting at the end of the eighteenth century, and throughout the nineteenth century, earned it the title Copperopolis.*

Padmore the Elder was engaged with this emergent industry from its earliest days. The origins of Copperopolis date from 1717 when Gabriel Powell, then steward to the Duke of Beaufort, advocated that a copper industry, rivalling that of Bristol, should be established in Swansea, the town being one days sailing closer to the copper mines of Devon and Cornwall, having abundant supplies of coal and having access to a harbour for the import of copper ore and export of refined copper. The Duke of Beaufort held the title to lands in the parish of Swansea and nearby Llangyfelach and Gabriel Powell had formerly been the portreeve for Swansea, a portreeve being an official possessing political, administrative and political authority over the town. In response to Powell's initiative, the first copper works in Swansea were established at Llangyfelach by a Dr Lane and Mr Pollard who owned copper mines in Devon and Cornwall. Kalmeter[xxi] recorded in this diary entry for the 13th November 1724:

> *South of Tavistock lies the William and Mary Copper Mine, which was not found until about six years ago and in the same year as the next two mines. The lode courses exactly east and west and begins on the bank of the River Tavy, running into the hill. There are three setts or sections, the first down the river, of which Dr Lane from Bristol holds 40 fathoms from Sir W Courtney, who as owner of the ground receives 1/7th of the ore… The third and easternmost sett on the same lode is held by Mr John Coster.*

Hughes records that the Llangyfelach copper works were designed and constructed by 'the eminent innovative engineer John Padmore' of Bristol. Interestingly the 3rd Duke of Beaufort, on whose land the works were built, was formerly styled the Marquis of Worcester until he inherited the title of Duke of Beaufort in 1714. The 2nd Marquis of Worcester, the designer of the Water Commanding Machine, was the great-great-grandfather of the 3rd Duke of Beaufort; was this coincidence?

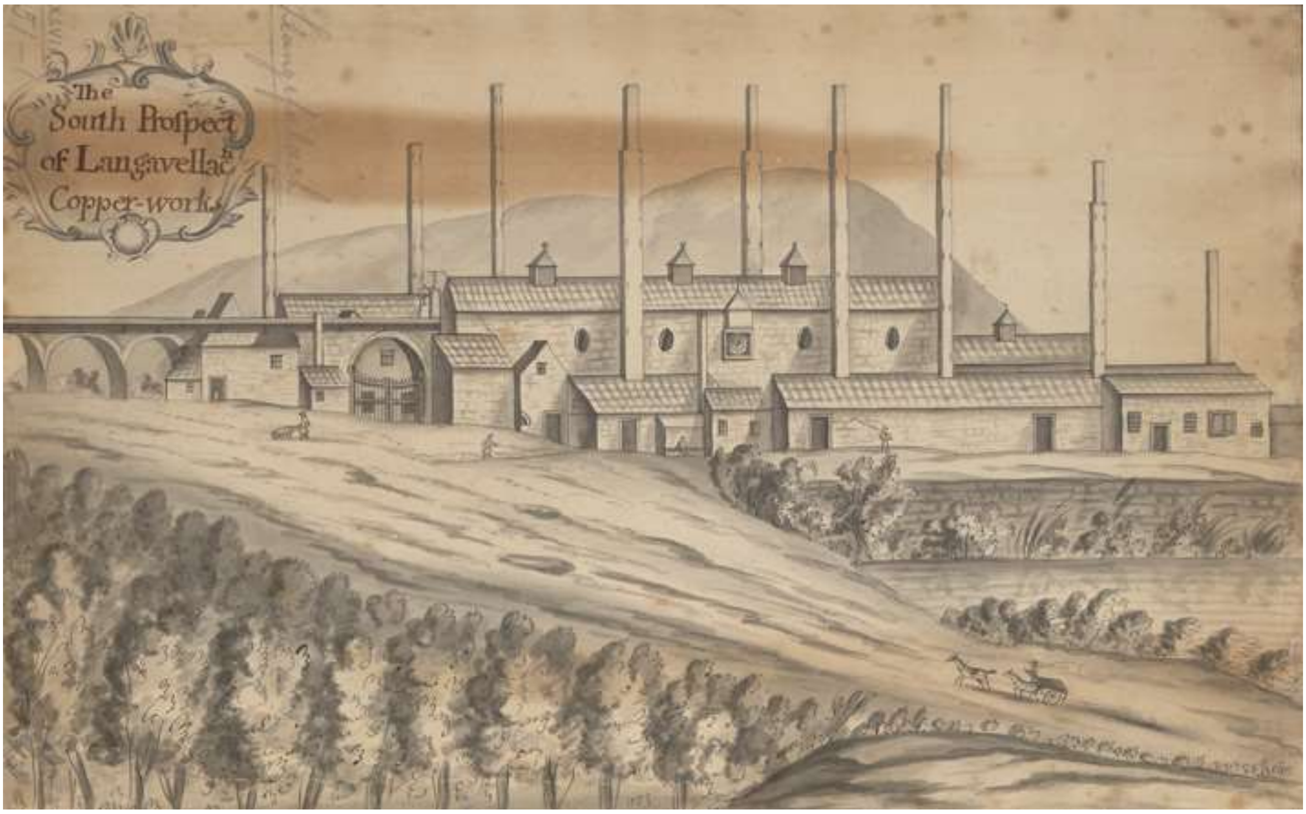

Figure 3 Llangyfelach Copper Works, built by John Padmore [British Library]

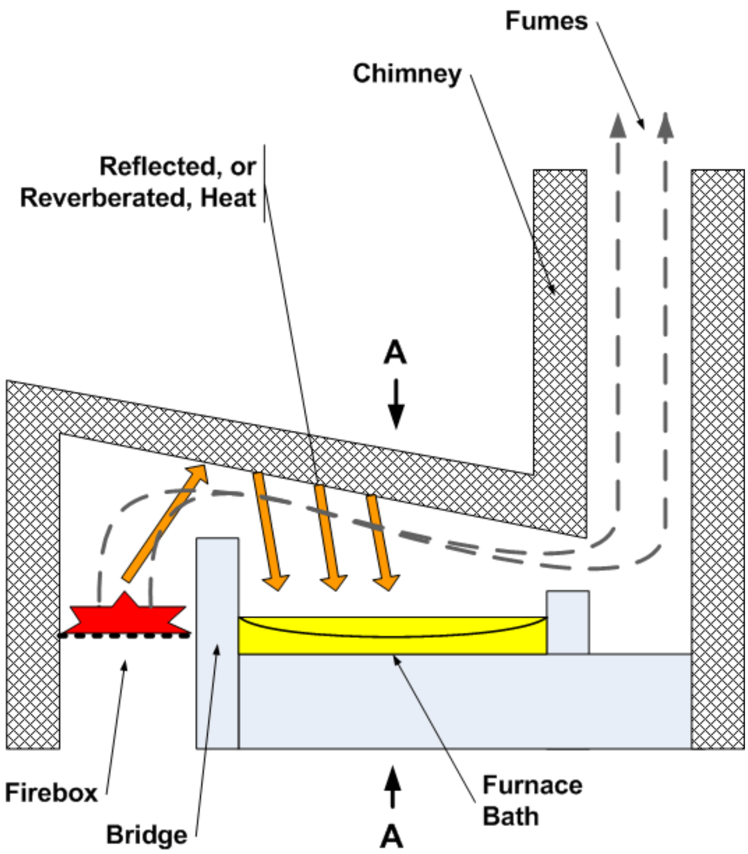

Figure 4 Reverberatory Furnace

The Llangyfelach works [Figure 3] drew heavily on Bristol practices, replicating the reverberatory copper smelting furnaces in St George. The most obvious features are the nine tall chimneys, each serving a reverberatory furnace. Coal can provide the necessary heat to smelt copper but releases sulphur which would impair the quality of the metal. The objective in a reverberatory furnace is to utilise the heat while preventing sulphur coming into contact with the metal. Coal is burnt in a fire-box, separated from the working-bed by a low wall (bridge) with the chimney constructed at the opposite end of the furnace to the fire-box [Figure 4]. The tall chimney creates a strong draft through the fire-box and over the working-bed, drawing smoke and sulphur along the furnace roof without coming into contact with the metal in the working-bed while the heat from the burning coal is reflected, or reverberated, off the roof of the furnace onto the working-bed.

The smelting process also releases arsenic, making hazardous working conditions within the smelting hall. Figure 3 shows four oval openings in the upper story of the smelting hall and three cupolas along the top of the roof which were probably ventilation features to remove noxious gases. In addition to the nine reverberatory furnaces, Figure 3 also shows an arched structure on the left leading into the smelting hall. This is either a viaduct for the delivery of coal or an aqueduct for the delivery of water. There appears to be a sluice arrangement installed at the structures junction with the smelting hall implying the latter and suggesting the presence of an over-shot waterwheel within the mill. One use of such a wheel could be to drive bellows connected to a blast furnace to raise the temperature within the furnace. Naturally ventilated reverberatory furnaces were capable of achieving the temperatures required for smelting copper (1500ºC) and the presence of a blast furnace suggests that either the operators were using a different smelting process for copper, or they were re-working the ore in an attempt to recover silver. Whichever process was in use, credit goes to John Padmore as 'chief mason' for the construction of the nine reverberatory furnaces in a common smelting hall, with ventilation systems to remove noxious gases, and the stone aqueduct. If our conjecture is correct that there is a father and son engaged in this work then it would be likely that John Padmore the Elder, then in his 50s, is the 'Chief Mason' and John Padmore the Younger is, in his late teens, his apprentice.

Padmore was clearly using techniques previously employed in St George. Was Padmore an observer of the practices in St George, or was he also involved in, or even in charge of the construction there? Evidence has yet to come to light to answer this question.

Lower Forest Copper Mill

Some 15 years later, in 1732, a John Padmore is again observed working in the River Tawe valley, but this time we are most probably looking at Padmore the Younger. The Swansea copper smelting industry was now well developed and Padmore is recorded constructing the Lower Forest Copper battery and rolling mill, built alongside the River Tawe, three miles north of Swansea. The layout of the mill has been reconstructed by Hughes [xxii] [Figure 5].

Profit lay in finished goods; pans, kettles and sheet metal. To produce such goods, a second type of mill was required; a battery and rolling mill. The technology used in South Wales was again copied from mills in the Avon Valley, which themselves drew on technology being used in continental Europe on the River Meuse (now in modern Belgium). The first three decades of the eighteenth century saw a rapid development in copper and brass manufacturing techniques in the Avon Valley and it is upon this experience that Padmore drew. The Bristol Brass Company had been founded in 1702. Over the next two decades a series of battery mills were built on the rivers Frome, Avon and Chew, including Baptist Mills [c.1705, headquarters of the Bristol Brass Company]; Chew Mill, Keynsham [c.1705]; Weston Mill, Bath [c.1711]; Woodborough Mill, Woollard [c.1711]; and Saltford Mill [1721]. The Lower Forest Mill shows a striking resemblance to Saltford Mill [Figure 5] [xxiii]. Padmore was clearly influenced by the Avon Valley practices and as a Bristol based millwright it is reasonable to assume that he was involved in building the Avon Valley mills, many of which were conversions of pre-existing fulling or grist mills adapted for battery and rolling.

The Lower Forest Copper Mill, in common with Saltford Mill comprise three elements: a battery mill; a rolling mill and an annealing furnace.

Battery Mill

Contemporary descriptions of continental and British battery mills plus archaeological evidence at Saltford enable comparisons with the Lower Forrest mill to be drawn. Galon, a French infantry colonel, conducted a survey of industry on the River Meuse and in 1749 published a description of a battery mill in ‘The Art of Making Brass’ [xxiv]. Galon states:

> *The manufacturing industries in general seem to be worth the attention of any industrious nation in order to bring forth the advantages which can result for the arts already in use. If we are to replace in our national industry the assistance we are now obliged to obtain from foreign countries such attention becomes indispensable.*

Copper and brass battery were evidently worthy of attention and the use of water power to drive a battery mill was a relatively recent invention, Galon noting:

> *It is known that before 1695, all brass at Namur was beaten by hand and that this year saw invention of Battery Mills driven by water. The first of these mills was established on the R. Meuse and its inventor was given exclusive privilege.*

The Bristol Brass Company acquired this technology relatively quickly, the first battery mills arriving in the Avon Valley around 1705. The copper was worked cold using rapid light battery and the design of the battery hammers was optimised for this purpose. A description of a battery mill is given by Day and Coverdale in BIAS Journal 46[xxv]. Such mills comprised one or more sets of water driven trip hammers, typically in banks of three[xxvi] [Figure 6]. Galon describes the hammers delivering 255 blows per minute; approx. 4 blows per second! An artisan sat on a bench alongside the hammer and manipulated a piece of copper beneath the striking hammer to raise a hollow-ware bowl, contemporary accounts describing the creation of a bowl being akin to a potter working clay.

Angerstein, a Swedish metallurgist, conducted a series of journeys through Britain, financed by the Swedish Association of Iron Masters, to observe industry. In his diary, published in 1754, he describes the Avon Valley[xxvii] battery mills, observing twelve hammers at Saltford[xxviii] driven by four undershot waterwheels each connected to a bank of three hammers. The Avon Valley rivers favoured the use of undershot water-wheels. By contrast, the River Tawe has a high fall of height. Padmore used this to his advantage by constructing a dam to create a mill pond which retained the head of water to drive a number of overshot waterwheels [Figure 5]. Overshot wheels are more efficient in their use of water and favour the conditions of a high fall but low flow-rate. The construction of such hydraulic structures mirrors the capability of Padmore the Elder seen at Llangyfelach and is a feature which shall meet again later in this paper.

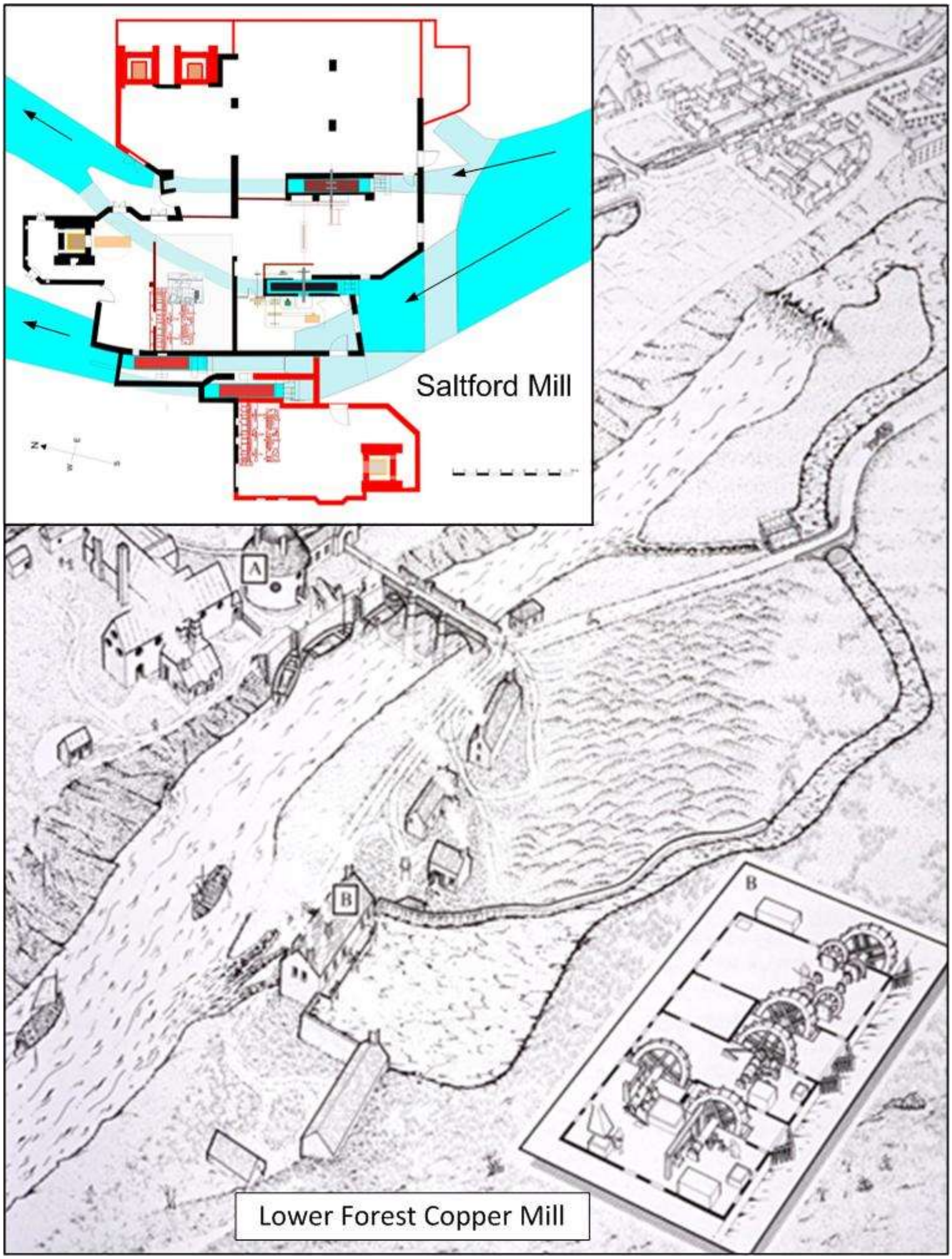

Figure 5 Lower Forest Copper Mill, 1732 [Hughes, Copperopolis].
Inset: Saltford Brass Mill, as modified for rolling c.1760 [SBMP]

Rolling Mill

Hughes suggests that the Lower Forest Copper Mill also contained sets of rolls for producing sheet, the rolls having being installed when the mill was built. If this assumption is correct, it would appear to be an early use of such technology in the copper and brass industry. The layout in Figure 5 displays many similarities to the later layout of Saltford Mill (Figure 5, inset) with three waterwheels dedicated to battery and two waterwheels dedicated to a tandem set of rolls.

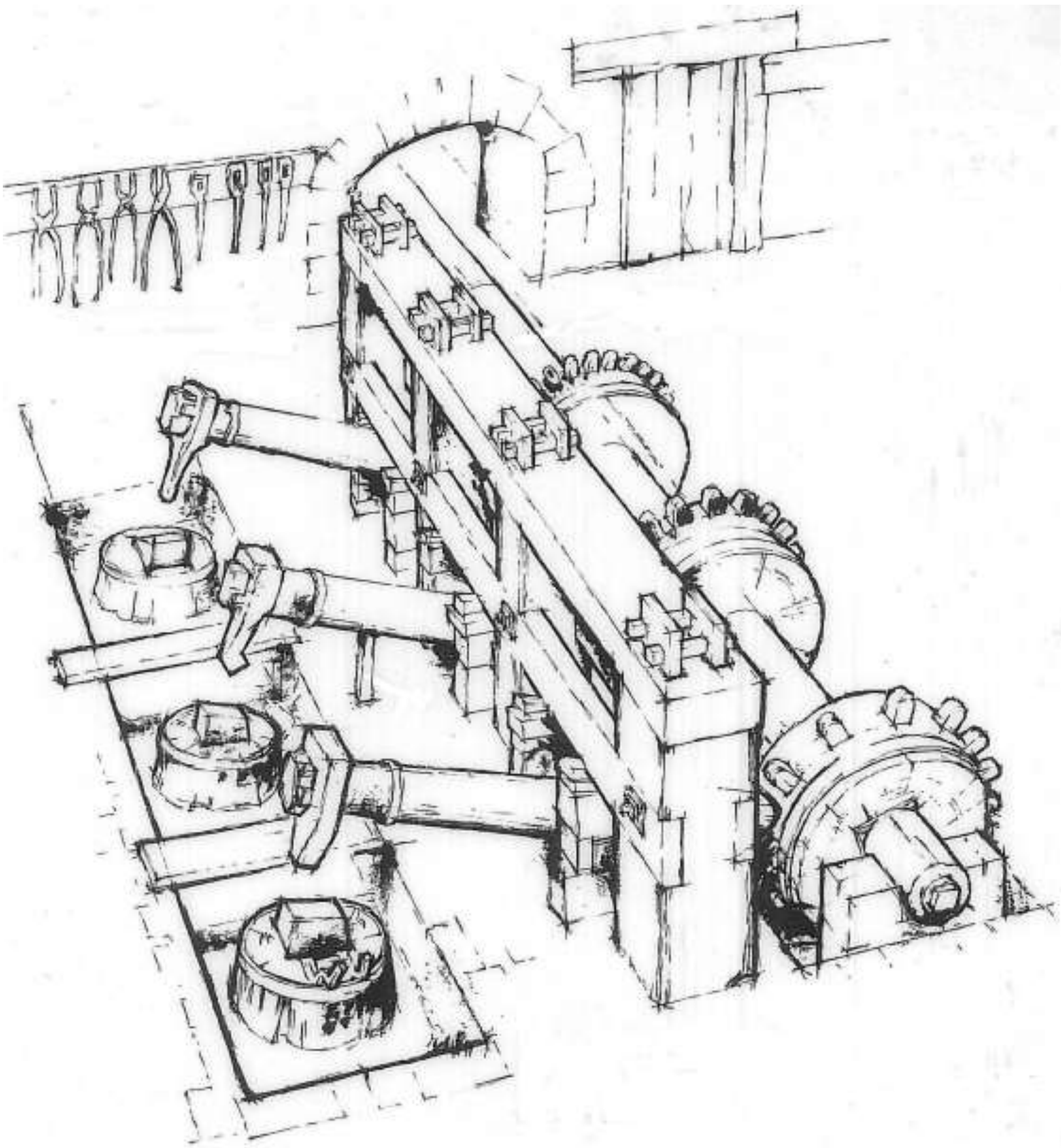

Figure 6 A set of three battery hammers, as installed at Saltford (© Joan Day)

Continental practice was to use battery hammers to produce sheet. Rolls first appeared in the Avon Valley c.1730, used in the manufacture of wire, the metal being rolled into long thin strips which were then slit and drawn through a series of dies to produce wire. Rolls were introduced at Saltford c.1760 when the demand for sheet metal increased, most probably in response to the demand for sheet metal for sheathing Bristol built merchant-ships destined for the West Indies to protect them from the Toredo Navalis or shipworm. Working in 1732, Padmore would appear to be applying the latest technology available in Bristol in the emergent Swansea industry.

Annealing

The third element of the Lower Forest Copper Mill is the annealing furnace. Copper is malleable and ductile at room temperature enabling it to be worked cold, however the metal hardens as it is worked making it less malleable, more difficult to work and ultimately to crack. The ductility and malleability of the metal can be recovered by annealing, which requires the metal to be heating to around 400^{o}C and subsequently cooled. An annealing furnace is observed in Hughes' reconstruction in Figure 5. The early 18th century was a period of rapid development in this area. Charcoal had traditionally been used for annealing as it produced a clean heat without the release of harmful sulphur which would have damaged the copper. In such furnaces the metal being worked is placed directly in the charcoal bed. Such a technique would not have worked with coal however. Nehemiah Champion was active in this area, having obtained a patent for an improved method of annealing in 1723[xxix], Champion's patent being for:

> *A new way of nealing the plates and kettles with pitt cole, which softens and makes the brass as tough and fine-coloured as any nealed with wood and wood-cole.*

Whether Padmore's copper mill of 1732 employed Champion's patent method or used traditional methods employing charcoal in an open furnace is not known, but a means of annealing using pit-coal would clearly have been advantageous in Swansea.

Floating Harbour

Some seventeen years earlier in 1715, a John Padmore is recorded as being engaged in another major civil engineering project, this time at Sea Mills, 4 miles north of Bristol where the River Trim enters the River Avon. The man in question is probably Padmore the Elder and the structure is a harbour wall enclosing a wet dock or floating harbour. This was only the third such structure in Britain after Rotherhithe[xxx] [1696] and Liverpool[xxxi] [1715] and nearly a century before Bristol's Floating Harbour [1809]. The remains of the Sea Mills structure [Figure 7] are now Grade II listed, the Historic England listing stating[xxxii]:

> *Harbour walls. c1715-20. By John Padmore. Rock-faced rubble walls… the first floating harbour on the Avon, in use from 1712, and the third in the country after Rotherhithe and Liverpool. It was used as a whaling station and by privateers until its closure in 1766.*

Figure 7 Sea Mills Harbour Wall. John Padmore. c.1715-20

Bristol is an ancient port, the mercantile centre of the city being located around Queen Square, with the two principal wharfs being Broad Quay on the River Frome and the Welsh Back and the River Avon, now both embodied within the Floating Harbour of 1809. The Avon has a very high tidal range meaning that before construction of the Floating Harbour ships would 'dry' at low-water and sit on the mud of the river-bed until re-floated on the next tide. This hampered loading and unloading as the ship and also necessitated a design of ship that could withstand twice daily drying out on the mud and remain near upright. This requirement gave rise to the expression 'Ship Shape and Bristol Fashion' being a vessel which was sufficiently strong, with the cargo securely stowed, to enable the ship to be beached twice per day. By the early eighteenth-century Bristol was considered the 'metropolis of the west' with far ranging trading connections. But Bristol was faced with the challenge of accommodating more and larger ships. There were many complaints from ship owners, in particular foreign owners, about their large vessels being kept waiting for berths or being stranded in the tidal mud with the potential for damage or, in the extreme, breaking the back of their ships.

Joshua Franklyn, a Bristol Merchant, conceived the idea of a wet dock to load and unload cargo whilst remaining afloat whatever the state of the tide. By locating the dock at Sea Mills, vessels would also avoid having to navigate the most difficult part of the Avon. The concept was sound but the reality did not live up to expectations, as observed by Latimer writing in 1893[xxxiii]:

> *In 1712 a company of adventurous Bristolians, of whom the most prominent was Joshua Franklyn, a merchant, resolved upon constructing a dock for the accommodation of shipping at Sea Mills. The vanity of human aspirations was exemplified in the terms of the lease of the required land, which (by virtue of a special Act of Parliament) was transferred to the undertakers by Edward Southwell, of Kingsweston, for a term of 999 years, at an annual rent of £81... With the exception of a dock at Liverpool, commenced in 1709, but not finished until 1717, the Sea Mills dock was the first mercantile Basin constructed in England. The adventure was divided into thirty-two shares, on which upwards of £300 each are said to have been called. Franklyn sank a large part of his fortune in the undertaking. There is no record of the opening of the dock. In a financial point of view, the place was a failure from the outset, the necessity of transhipping cargoes into barges overriding the advantage it possessed of keeping vessels afloat at low-water.*

The concept failed because adequate roads did not exist to transport cargoes between Bristol and Sea Mills. The market for inward goods was in Bristol and the warehouses for storage of cargoes were located around Broad Quay and Welsh Back in central Bristol. Transport of bulk cargo by road was impractical; so, cargoes were transhipped to barges for shipment into Bristol. This undermined the main advantage of the dock and the scheme failed. The concept of a floating harbour was nevertheless robust and Padmore's structures clearly met their technical objective, being in use until 1766. Sea Mills failed not because of the engineering concept but because of its dislocation from the established mercantile centre of Bristol. A similar scheme was attempted in 1768 by William Champion, the son of Nehemiah Champion, who built an enclosed dock at Hotwells. The dock was bought by the Society of Merchant Venturers in 1770 and became known as Merchants Dock. The scheme was not a great success however, again because, although closer than Sea Mills, it was still too far from the main trading centre.

The technical objective was to construct a wall across the River Trim close to its confluence with the River Avon. Lock gates were built into the wall such that ships could enter the enclosed basin at high tide. As the tide turned, the gates were shut leaving the ships within the basin where they could be unloaded and loaded whilst remaining afloat. The wall, 60.5 m long, enclosed a dock of approx. 7,500 square meters (2 acres) accessed by an entrance gate 9.5 m wide. The dock gates were probably of the mitre type, i.e. two gates which close together in a shallow 'v' with water pressure within the dock holding the gates shut and forming a tight seal. This arrangement is seen on most canals in Britain, including the Avon Navigation and the Kennet and Avon Canal.

Comparing the Rotherhithe, Liverpool and Sea Mills schemes, Rotherhithe was the largest in area at 12.25 acres, with Liverpool, 4 acres, and Sea Mills, 2 acres. (As a comparator, Bristol's 1809 Floating Harbour is approx. 70 acres). Although smaller in area than Liverpool, the technical challenge at Sea Mills was similar. Both ports experience a very high tidal range of around 30 feet. Both therefore needed a robust structure to withstand the head of water retained within the dock at low tide. Construction at both was restricted to working at low tide to establish the foundations for the dock wall. At Sea Mills, Padmore also had to contend with mud. Ideally, excavations would be dug to expose bed-rock upon which the firm footings could be constructed. Alternatively, the mud bank could be piled, the bed dug out behind the piles and a stone and mortar bed constructed on which the dock wall could be built. Each tide would bring with it a new layer of mud which would cover the previous work. The fact that 300 years after they were built, Sea Mills' walls remain stable and upright is testimony to Padmore's work.

The Rotherhithe scheme was a repair facility rather than a mercantile dock, so although technically similar to Sea Mills its envisaged use was different. It did not have attendant warehouses, instead it was conceived as a place for accommodating ships "without the trouble of shifting, mooring or unmooring any in the dock for taking in or out any other"; it was a non-tidal sheltered anchorage for repair work. The concept at Liverpool was to use the basin as a mercantile facility from the outset. Here the plan succeeded for a number of reasons. Liverpool was an emergent international port unencumbered with legacy infrastructure. The city's new mercantile infrastructure could grow around the basin. The benefit of the basin was that a ship could unload in 1.5 days as opposed to the 12 to 14 days needed when unloading was restricted by the tide.

Liverpool merchants also funded waterway links with its hinterland by making tributaries to the River Mersey navigable, linking the port to markets and centres of manufacture. The Irwell and Mersey navigation (opened 1734) linked Liverpool with the coal reserves and textile manufacturing centre of Manchester. The River Weaver provided a navigable waterway to Cheshire and its reserves of salt. The enabling of the transport of goods by improved river navigations were the precursor to the great canal building boom of the late eighteenth and early nineteenth century. It is in this field that we next observe John Padmore engaged.

The Avon Navigation

Buchanan gives a comprehensive account of the Avon Navigation in 'The Avon Navigation and Inland Port of Bath'[xxxiv]. The eighteenth-century surgeon and antiquarian William Barrett observed that[xxxv]:

> *Boats of burden used of old to carry goods from Bristol to Bath, until the river was obstructed by wears, mills, & c. as appears by Clause 4, Edw p 1, m 4, who ordered the removal of them but it was again made navigable in the year 1727.*

John Padmore was engaged in the construction of at least three structures on the Avon Navigation, it not more.

The Rights of Navigation had been a significant issue in England since the earliest times, indeed Clause 33 of the Magna Carta addressed the principle of free passage along England's rivers. In 1215 the major obstacles to navigation had been fish weirs but in later centuries millers also raised weirs to create a head of water to power their mills. Over the following centuries statues were passed which sought to enable the free passage of rivers, typified by the statute of Edward III[xxxvi]

> *New Wears shall be pulled down and not repaired. Whereas the common passage of boats and ships in the great Rivers of England be oftentimes annoyed by inhansing Gorces, Mills, Wears, Stanks, Stakes and Kiddles in great Damage of the People; it is*

accorded and established that all such Gorces, Mills, Wears, Stanks, Stakes and Kiddles, which be levied and set up in the time of King Edward the King's Grandfather and after whereby the said ships and boats be disturbed that they cannot pass in such river as they went shall be out and utterly pulled down without being renewed.

As recorded by Boyes[xxxvii], in 1411, sea-going vessels had been 'capable of passage from Bristol to Bath for the carriage of wine, com, salt, wool, skins of wool, cloth and osiers'. However, the use of water power for grinding flour and grist, and the use of water power for driving fulling or tucking mills for the cleaning and felting of woollen cloth, encouraged mill owners to raise the level of their weirs to increase the power of their mills.

By the early 1700s, there are seven weirs between Bath and Bristol: Twerton upper and lower; Kelston; Saltford; Swineford; Keynsham and Hanham. In the early decades of the eighteenth century three of these had been acquired by the Bristol Brass Company: Twerton Upper weir powering a brass battery mill; Kelston weir powering Saltford brass battery mill; and Keynsham weir powering a brass wire mill. Swineford weir and mill was operated by John Coster for rolling copper sheet. Saltford weir was later to be acquired by William Champion's Warmley copper and brass company and used to power Kelston brass battery mill. Five of the seven weirs were therefore in use by the Avon valley copper and brass industry. John Padmore was a shareholder in the Bristol Brass Company and these mills were all similar to Lower Forest Copper Mill. John Padmore the Younger either observed these newly constructed mills and took the technology to Swansea, or Padmore had been involved with the construction of these mills themselves.

Throughout the 17th century schemes to improve the navigation had been promoted but failed. The prospect of making the River Avon navigable again from Bristol to Bath had been proposed as early as 1619 when 'Letters Patent' from James I were granted to the Mayor and Corporation of Bath to make the Avon navigable between Bath and Bristol[xxxviii], but this initiative was not acted upon. Support for the navigation was not unanimous, opponents included: land owners who feared for the value of their property; mill owners (most notably the copper and brass companies) who feared that competing demands for water would starve their mills of the necessary power; and traders who feared that improved transport would place old established supplies to the East of Bath at a disadvantage. A Bill eventually reached the statute books in 1712 and Bath Corporation granted the powers conferred on them to a new body of proprietors. Their treasurers were Dr Charles Bave (a Bath Physician), Thomas Atwood (a plumber and glazier of Bath) and Ralph Allen (the Bath entrepreneur and philanthropist, noted as post master of Bath and for his stone quarries in Combe Down). Ralph Allen and John Padmore's paths were to cross again later in the story. But three other notable names amongst the proprietors had connections to Padmore: Dr John Lane, the Bristol doctor and metallurgist who had established the Llangyfelach Copper Works in 1717; Thomas Tyndall [b. 1685], the brother of Onesiphorus Tyndall [1689 - 1757], to whom John Padmore later left his shares in the Bristol Brass Company and Robert Coster, the brother of Thomas Coster, also a partner in the Bristol Brass Company, and son of John Coster, the owner of Swineford Mill.

Records show that Padmore the younger was engaged on at least three structures on the Avon Navigation. The pound lock at Weston, the bridge over the Locksbrook Cut at Weston and the pound lock at Keynsham. Historic England's citation for Weston Lock[xxxix] states;

> *Canal lock with gates. Early C18, the Avon Navigation was opened in 1727. Engineer, John Padmore; promoters Ralph Allen and John Wood the Elder. Ashlar or dressed limestone block, some rubble, wooden gates, some cast iron detail. Two pairs of original-form heavy gates have the beams contained on the north side by an arc of stone curbing set in the rising embankment. The long lock basin walls extend approximately 55m, and are brought to flush rounded copings in heavy stone; at the upstream end the walls flare out to quadrant returns, and at the downstream end the south wall has a flight of eleven very steep steps, against a set back retaining wall stopped to C20th sheet piling. The north wall also has a steep set of ten steps to a narrow landing, carried to a retaining wall which returns to a quadrant, with a further run of approximately 35m of high retaining wall in ashlar with rounded coping, brought above the path level. This lock remains mostly unaltered. It was built on a short length of canal, sometimes known as Locksbrook Cut, to by-pass a bend and weir in the River Avon.*

Historic England's citation for Weston Cut Bridge[xl] states:

> *Accommodation bridge over canal. Dated 1728 (the Avon Navigation was opened in 1727). By John Padmore, engineer. Squared and coursed rubble, some ashlar. A single-span bridge with slightly elliptical and eccentric arch, with lower springing to the north than the south side, perhaps resulting from early settlement. The arch in concentric ashlar voussoirs, and, on the east side, a near-central projecting keystone with date incised; the west side also has an off-centre projecting keystone, but without date. The*

parapets rise to a slight peak at the centre of the span, with dressed copings, and are swept round to short returns at the south end. At the north end, adjacent to The Dolphin public house (qv), the parapet walls are stopped square, and short straight lengths of raked ashlar wall with flush rounded copings abut on each side. The short length of canal here, sometimes known as Locksbrook Cut, bypassed a bend and weir in the River Avon.

Weston Lock and Bridge are the subject of the painting at Figure 8.

Figure 8 Locksbrook Cut, showing the Weston Lock and Weston Lock Bridge

Buchanan[xli] states:

On 1 November (1725) the Committee ordered that Mr Hoare should give instructions 'to Mr Padmore for a Draught of the Gates to be erected at Keynsham', and asked for a review of the siting of the wharf at Keynsham, which they thought inconvenient... in the middle months of 1727... the Bristol engineer John Padmore was, through his technical skills, playing an important part in the execution of the 'grand design'

Mr Hoare was John Hoare of Newbury who was employed by the proprietors of the Avon Navigation for the 'Direction and Chief management of the Works'. John Hoare had successfully constructed the Kennet Navigation (1718-23) and so was recognised as an expert in this field. Work commenced at Hanham, where Padmore the Elder had been employed by the Bristol Water Company. The sub-contacting of John Padmore for the construction of pound locks reflects his experience at Sea Mills, both requiring substantial civil engineering to retain the pressure of water and earth. The mitre pound lock gates are also suggestive of the gates that once would have closed the entrance to the Sea Mills dock.

Ralph Allen’s Tram-Way

The Avon Navigation provided a transport system capable of moving bulk and heavy material between the centre of Bath and the docks in Bristol. In 1726, the year before the navigation was opened, Ralph Allen began buying land on Combe Down and by 1731 owned almost all of it[xlii]. In 1729 he acquired quarrying rights for 100 years. But if he was to exploit the reserves of stone, he required an efficient means of transporting the material from his quarries in the hills to the south of Bath to building sites in Bath and further afield. With that objective in sight, Ralph Allen came to dominate the Avon Navigation Committee, the Navigation being a key piece of infrastructure to enable him to transport his stone to Bristol and beyond. But the stone had first to be moved to the River Avon. As observed by Willies, Redvers-Higgins and Wain[xliii]:

> *'Ralph Allen's substantial investment into quarrying at Combe Down from about 1729 had an immediate and increasing impact on both the surface landscape and underground... most of his investment went into improving stone handling and transport system between the quarries on Combe Down and his wharf, stone yard and building sites in Bath, a distance of some two miles down a fairly steep slope.*

Padmore the Younger was to play a key part in these improvements designing and building an inclined tram-way to lower stone to the river and designing and building cranes which were capable to loading large blocks of stone onto river barges. Ralph Allen established a stone-yard and wharf at Dolemeads on the River Avon below his lands at Combe Down. Figure 9 shows a close up of a 'a perspective view of the city of Bath'[xliv] dated c.1734 which clearly shows Ralph Allen's stone-yard and wharf in Dolemeads with the Old Bath Bridge in the background and the Southgate area of Bath across the river.

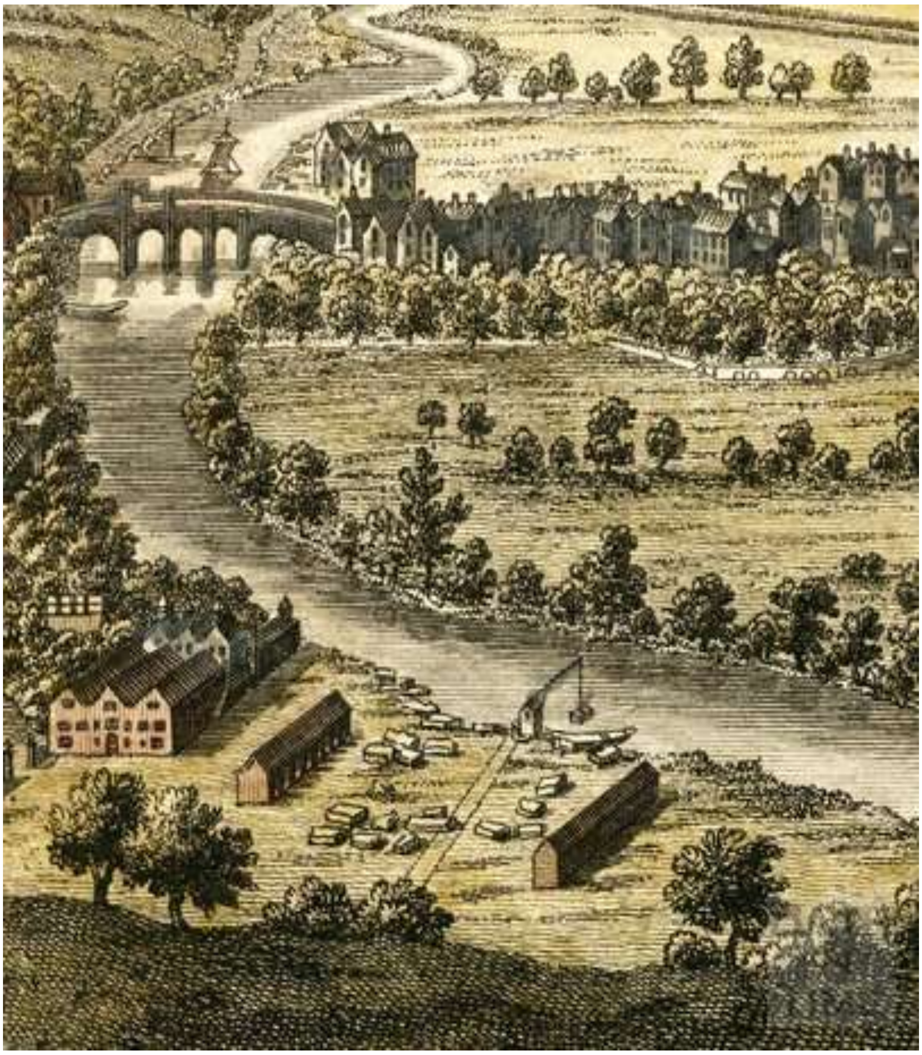

Figure 9 Dolemeads Wharf and Stone-Yard (Courtesy of the Victoria and Albert Museum)

Richard Jones, the Clerk of Works to Ralph Allen, writing in 1763 stated:

> *"We sent away 1800 tunns a year... The motion of lowering the stone is one of the most expeditious of any thing of its kind, and allowed by the Curious to be a Master piece of Mechanism, to which Crane ye Stone in large Blocks seldom less than 5 or 6 Tun at a time, to descend from the Quarries, at least a Mile and a half, by Machines contrived at the Charge and Expence of Mr Allen the Proprietor of it, on which Account the Stone is Sold for a fourth part less than heretofore, to the great Advantage of the Public and Gentlemen that use it"*

The means of lowering the stone was devised by Padmore the Elder. The 'machines contrived' for this purpose are shown in an engraving by Anthony Walker (c.1750) reproduced at Figure 10[xlv]. The 'machines contrived' were an inclined tram-way.

Figure 10 Combe Down Tram-Way (Courtesy of the Museum of Bath Architecture)

Padmore required considerable ingenuity to design a tram-way which incorporated: a means of controlling the rate of descent of blocks of stone weighing 5 or 6 tonnes; a means of controlling the direction of travel of those blocks; a means of raising heavy blocks of stone from the mines in Combe Down to the summit before making their descent; and a means of raising the empty wagons back up to the summit for the next load. To understand how Padmore achieved these functions we are fortunate in having Desaguliers 'A Course of Experimental Philosophy'[xlvi] of 1734. A plate from Desaguliers book is reproduced at Figure 11 and gives an insight to the workings of Padmore's Tram-Way.

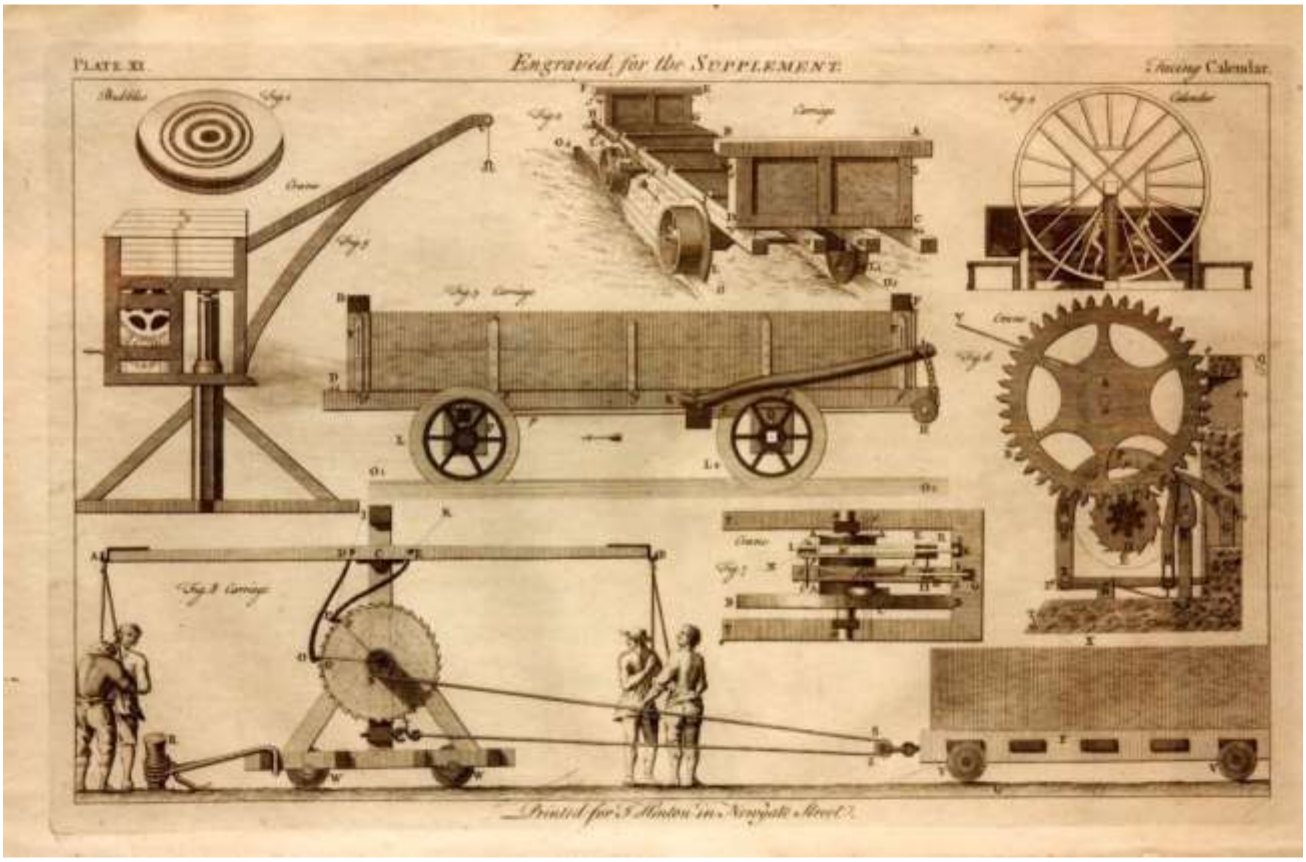

Figure 11 Plate from 'A Course of Experimental Philosophy'. Vol 1 J T Desaguliers. 1734 (Courtesy of the Museum of Bath Architecture)

In the centre of the plate we see one of Padmore's carriages and evidence of his solution to the first problem of controlling the speed of descent. Above the rear wheel (to the right in the picture) we can see a lever which operates on a wooden break block rubbing on the wheel. If we look at Figure 10 we can see men applying pressure to the breaks on both descending wagons so controlling the speed of descent. Ralph Allen Drive has an average gradient of 10% and a maximum gradient of 18%. Controlling the speed of descent of 6 tons of stone using a lever around 2 meters long acting on a wooden break block must have been quite a challenge!

Above the profile view of the carriage we can see Padmore's solution to the problem of controlling the direction of the load. The carriage wheels are flanged and run on timber rails. The rails are square, not bevelled as are modern railway lines, hence the direction of the carriage was controlled by the flange rubbing against the track. The rate of wear must have been quite high, but it is clear that the tram-way operated for many years, Desaguliers writing his account in 1734 and Jones writing his account in 1763.

Certain accounts state that horses were used to pull the carriages back to the summit for re-load. Desaguliers however shows two other devices which could be used for raising empty carriages at a fast rate or loaded carriages at a low rate using man-power,

To raise heavy loads, presumably raising fully loaded carriages from the mines to the summit of the tram-way, a ratchet driven winch is described at the bottom of the plate, operated by four men. The machine is mounted on rails, hence mobile, and secured in position by being tied to a stake (R) driven into the ground. To raise the load the two men on the left pull down lever (A) causing the right-hand ratchet arm (E-P) to turn the centrally mounted winch (N) clockwise so raising the load. When at the full extent of their travel the two men on the right would pull down lever (B) causing the left-hand ratchet arm (D-O) to continue the motion.

To raise lighter loads, a treadmill is shown in the upper right-hand corner of the plate. By this means two men can raise a lighter load at higher speed. We shall return to this concept of a two-speed lifting mechanism shortly in Padmore's design of cranes.

Cranes

Turning again to Figure 9, Samuel and Nathaniel Buck's image of the Dolemeads Wharf, we can see a crane being used for loading stone onto barges which has been delivered to the stone yard by Padmore's tram-way. This was again of Padmore's design to the extent that he is shown with a model of the crane in his portrait shown at Figure 1. This crane was one of two cranes that we shall discuss in this paper, but most likely one of several built to Padmore's specification. The two cranes we shall discuss here are the Dolemeads Wharf Crane and the Great Crane in Bristol.

Dolemeads Crane

Images of the crane can be seen on the left and right of the Desaguliers plate, the characteristics of which are: it is mounted on a central post, akin to a post windmill; the crane can rotate around the post enabling it to slew; the crane contains a gearing arrangement to provide mechanical advantage to the operators; and the crane contains a ratchet mechanism to prevent run-away of the load. A model of the crane can be seen in the Museum of Bath Architecture, shown at Figure 12. The crane is possibly the machine described in an advertisement of 1769 which stated:

'TO be Disposed of, a Round-about CRANE constructed by the late ingenious Mr. Padmore, capable of raising two Tons Weight by two Men only, and will be sold very cheap, being obliged to be removed in a limited Time. Any person willing to treat for the same may receive further Information by applying to William Biggs, on the Quay, Bath, who will shew the Crane. It is situated on the Bank of the River Avon, very Convenient for Water Carriage to Bristol'.

This may be Ralph Allen's crane whose business declined after his death in 1764.

Figure 12 Dolemeads Crane (Courtesy of the Museum of Bath Architecture)

Great Crane, Bristol

A second crane using very similar principles but constructed on a larger scale was the Great Crane erected alongside the Mud Dock in Bristol (Figure 13). In his 'History of Bristol'[xlvii] [1824], John Evans records:

1733: The Great Crane near the Gibb erected by Mr. Padmore, and the Mud-Dock completed, at the expense of the Society of Merchants.

The crane is also recorded by Cooke[xlviii] in his British Travellers' Pocket Dictionary [1820]:

On the western side of the Mud-Dock is the great crane, erected on fourteen pillars, cased with iron, by the ingenious Mr Padmore; a curious piece of mechanism, and worthy of *observation. Cranes of the same internal construction are erected in proper situations for loading and unloading, which are all numbered, for the more readily finding the subjacent vessels.*

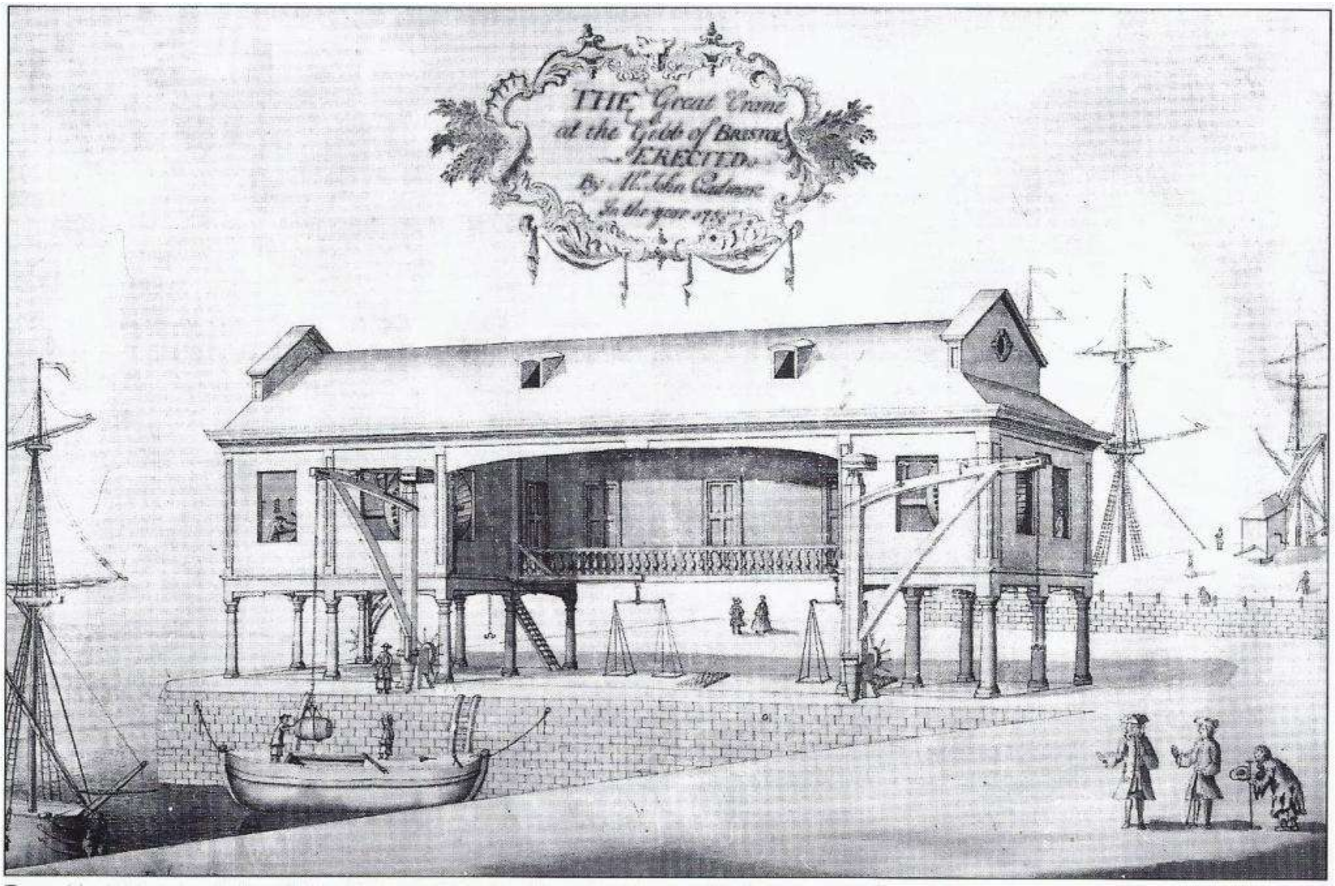

Figure 13 Great Crane, Bristol - 1733

In Vol II of 'A Course of Experimental Philosophy'[xlix] [1744] Desaguliers provides a description of Padmore's Great Crane:

A short account of the crane at Bristol will show what is to be dome in that case. The great crane set up there by the late Mr Padmore is moved by a very small trundle or lantern, whose rounds take the cogs of a very large wheel, so as to have the power of two men sufficient to raise the heaviest goods out of a ship, spending the time necessary in the operation: But as there are a great many bales of goods 5 or 6 times lighter than the heaviest goods, and it would be loss of time to employ the crane in the manner already described to raise them; there is a contrivance to loosen the lantern or trundle from the cogs and then the wheel being also a walking wheel, the same men would get into it, in which case they have power sufficient to raise small goods 5 or 6 times faster than the heaviest; so that the crane becomes of general use.

In the Great Crane, we can see embodied many of the features employed in earlier devices. The crane is a two-speed device, employing a geared arrangement, as used on Dolemeads Wharf, to provide mechanical advantage for heavy loads and a tread-wheel or walking-wheel, as used on Ralph Allen's Tram-Way, for lifting lighter loads at higher speed. The crane jibs were able to slew, but this time the mounting arrangements are part of a larger structure 'erected on fourteen pillars'. The crane also employed the ratchet mechanism see on the Dolemeads Crane, as recorded in 1764 by Ferguson[l] in his 'Description of a new and safe crane', invented by Mr James Ferguson, FRS, 1764:

> *Whilst the weight is drawing up, the racch-teeth of a wheel slip round below a catch or click that falls successively into them; and so hinders the crane from turning backward, and detains the weight in any part of its ascent, if the worker should happen accidentally to quit his hold of the winch, or choose to rest himself before the weight is drawn up. The catch, in this crane, is constructed much in the same way as in the great crane at Bristol, invented by the late Mr Padmore, of that city.*

The crane caught the eye of Daniel Defoe who in his 1742 'Tour' refers to the Great Crane being 'the workmanship of the late ingenious Mr Padmore'.

Epilogue

When John Padmore the younger died in 1734 he was in his mid-30s and at the peak of his career. He had completed the Great Crane in Bristol the year before his death and two years earlier had completed the Lower Forest Copper Mill in Swansea. He was a shareholder in the Bristol Brass Company at the heart of a rapidly developing industry and was clearly close to Nehemiah Champion and Onesiphorus Tyndall. Nehemiah Champion was a respected technologist and merchant. Onesiphorus Tyndall was a Bristol merchant and destined to become the senior partner of the Old Bank, the first bank to be established in Bristol. Padmore was also clearly respected by Ralph Allen, John Padmore's portrait being recorded in an inventory of Ralph Allen's in 1769. This is probably the portrait now held by the Victoria Art Gallery in Bath which shows a man, clearly proud of his inventions and achievements, showing off a model of the crane which had been installed in Ralph Allen's stone-yard at Dolemeads Wharf. Some year later in 1740, Mr Padmore is recorded in the minutes of the Committee of the Society of Merchant Venturers[li], his estate offered to sell a crane 'which is already made'.

The careers of John Padmore the Elder and John Padmore the Younger spanned more than 40 years and involved the application of steam to raise water, the construction of harbours and waterways, the construction of mills, the construction of railways and the construction of cranes. Working over a century before that great engineer IK Brunel, the Padmores were ingenious men and polymaths well ahead of their time.

Perhaps the last word should be left to Daniel Defoe, describing in his ‘Tour of Great Britain’: the Great Crane of Bristol is 'the workmanship of the late ingenious Mr Padmore'.

[i] A tour thro' the whole island of Great Britain. Daniel Defoe. 1742

[ii] Will of John Padmore, Millwright of Barton Regis. PROB 11/672/116. The National Archive.

[iii] The Annals of Bristol in the Nineteenth Century. John Latimer. 1900.

[iv] Auction catalogue of the contents of Ralph Allen's Prior Park in 1769, a 'portrait of Mr Padmore, in a painted frame'

[v] Martin Watts. John Padmore's Cranes at Bath and Bristol. BIAS Journal 08

[vi] The Annals of Bristol in the Nineteenth Century. John Latimer. 1887

[vii] A New History of Gloucestershire by Samuel Rudder. 1779. St. Georges.

[viii] A new analysis of the Bristol Waters: John Shebbeare, 1740

[ix] A Chronological Outline of the History of Bristol and the Stranger's Guide to its Streets and Neighbourhoods. John Evans. 1824

[x] Topography of Great Britain or A British Traveller's Pocket Directory. G A Cooke. 1820

[xi] A New History of Gloucestershire by Samuel Rudder. 1779.

[xii] A new analysis of the Bristol Waters: John Shebbeare, 1740

[xiii] The Annals of Bristol in the Nineteenth Century. John Latimer. 1887.

[xiv] The Miners Friend or An Engine to Raise Water by Fire by Captain Thomas Savery. 1702

[xv] Century of the Names and Scantlings of Inventions by me already practised. Edward Somerset, Second Marquis of Worcester. 1663

[xvi] The Growth of the Steam Engine. Professor R H Thurston. Stevens Institute of Technology. 1878

[xvii] Patent. Reverberatory Furnace. Hutchinson & Lord Grandison. October 1678

[xviii] The Cornish Mining Industry, a brief history. J A Buckley. 1992. pg 13

[xix] The Avon Valley Copper and Brass Industry. Day and Coverdale. BIAS Journal 46. 2013

[xx] Copperoppolis, the landscape of the early industrial period of Swansea. Stephen Hughes. Royal Commission on the Ancient and Historical Monument of Wales. 2000. Pg 20.

[xxi] The Kalmeter Journal – The Journal of a Visit to Cornwall, Devon and Somerset in 1724-25. Henric Kalmeter

[xxii] Plan: Lower Forrest Copper Mill / Beaufort Tinplate Works. West Glamorgan Archives Service. Neath Abbey Ironworks Collection. D/D NAI M/77/2.

[xxiii] Saltford Brass Mill Project. www.brassmill.com

[xxiv] The Art of Converting Red or Rosette Copper into Brass by means of calamine stone, its casting into slabs, its battery under the hammer and its drawing into wire. Messes Galon & Duhamel du Monceau. 1749/1764

[xxv] The Avon Valley Copper and Brass Industry. Day and Coverdale. BIAS Journal 46, 2013.

[xxvi] Bristol Brass: The History of the Industry. Joan Day. 1973. p166

[xxvii] RR Angerstein's Illustrated Travel Diary, 1753-1655. Journey 5C. Bristol to Pontypool.

[xxviii] RR Angerstein's Illustrated Travel Diary, 1753-1655. "On the road from Keynsham to Bath there is yet another (battery mill), comprising three workshops and 12 hammers. 275B.

[xxix] Patent 454. A New Way of Nealing. Nehemiah Champion. 1723

[xxx] Rotherhithe. Howland Great Wet Dock. 1695-99. Excavated 1696.

[xxxi] Liverpool Old Dock, Thomas Steer's Dock started 1709, completed 1715.

[xxxii] Historic England List Entry 1202563. Harbour WAlls of Sea Mills Docks. https://historicengland.org.uk/listing/the-list/list-entry/1202563

[xxxiii] The Annals of Bristol in the Eighteenth Century. John Latimer. p98

[xxxiv] Brenda Buchanan. The Avon Navigation and the Inland Port of Bath. Bath History. Vol VI. 1996. pp. 63-107.

[xxxv] William Barrett, The History and Antiquities of the City of Bristol (Bristol,1789), pp.54.

[xxxvi] Edw(ard) III. stat 4. AD 1350. New Wears shall be pulled down and not repaired.

[xxxvii] Boyes, 'Legislative History of River Navigation', p.77.

[xxxviii] John Latimer, *The Annals of Bristol* (Bristol, 1900-08), Vol. 1, The Seventeenth Century, pp.71, 268-9; Willan, *River Navigation,* pp.24-51, also 'Bath and the River Avon', pp.139-40.

[xxxix] Historic England. Weston Lock. List entry Number: 1395660

[xl] Historic England. Weston Lock, Bridge. List entry Number: 1395658

[xli] The Avon Navigation and the Inland Port of Bath, Brenda Buchanan.

[xlii] A Brief History of the Stone Quarries at Combe Down. David Workman. Journal of the Bath Geological Society. No 23, 2004

[xliii] Finished Labour of a Thousand Hands. Willes, Redvers-Higgins and Wain. 2011. p42

[xliv] A Perspective View of the City of Bath, c. 1734. Samuel and Nathaniel Buck. Courtesy of the Victoria and Albert Museum.

[xlv] Engraving by Anthony Walker of Prior Park: The Seat of Ralph Allen. Courtesy of The Building of Bath Museum.

[xlvi] A Course of Experimental Philosophy. John Theophilus Desaguliers. Vol I. 1734

[xlvii] A Chronological Outline of the History of Bristol and the Stranger's Guide through its streets and neighbourhood. John Evans, Printer. 1824

[xlviii] Topography of Great Britain or British Traveller's Pocket Directory. Vol II. Somerset and Dorsetshire. G A Cooke. 1820

[xlix] A Course of Experimental Philosophy. John Theophilus Desaguliers. Vol II. 1744

[l] A description of a new and safe crane which has four different powers', invented by Mr James Ferguson, FRS, 1764

[li] Minutes of Committee of the Society of Merchant Venturers. 18 Oct 1740. Mr Padmore attended and offered to sell a crane 'which is already made'.