3D-Metamodeling Polhem's *Laboratorium mechanicum*

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During the latter half of the 18th century, the Royal Swedish Model Chamber in Stockholm—of which there sadly exist no images—counted as one of the finest physical model collections in Europe. It was open to the public and attracted a number of foreign visitors—like the German scholar Johann Beckmann. He was a man of enlightenment, and today a well-known figure within the history of science and technology. After a visit to the model chamber, Beckmann stated in his travel diary: "Es ist ein sehr grosser Saal, auf welchem mehr als 100 Modelle stehn … Die mehrsten sind mechanische."

Beckmann was mostly impressed by the Swedish scientist and pre-industrial inventor, Christopher Polhem's so called mechanical alphabet. These small wooden models were designed and built to illustrate different mechanical principles. Initially, the alphabet consisted of some 80 models of machine elements like the lever, the wheel and the screw, and Beckmann seems to have understood the basic ideas behind these wooden models immediately: "Das so genante mechanische ABC war artig, es waren nämlich kleine Modelle von allen Arten der Bewegungen und einfachen Maschinen, die die Anfangsgründe der ganzen Mechanik enthielten."

When Beckmann visited Sweden, Polhem had passed away some 15 years earlier. Polhem was principally a practical man, but also an original thinker on science, engineering and philosophy. 20,000 of his manuscript pages have survived. The Royal Model Chamber was a precursor to Polhem's, *Laboratorium mechanicum*, a collection of educational, miniature wood models of basic mechanic principles, equipment, hoisting machines and water gates invented (mostly) by himself. Set up in the late 1690s, the *Laboratorium mechanicum* was a facility for training Swedish engineers—before any formal university or polytechnic education existed—as well as a laboratory for testing and exhibiting Polhem's models and designs.

According to Christopher Polhem, *mechanics* was the foundation of all knowledge. As a pre-industrial inventor working during the early 1700s, he sincerely believed that *physical models* were always superior to drawings and abstract representations. Since a writer naturally had to know the alphabet in order to create words and sentences, Polhem argued that a contemporary *mechanicus* had to grasp a similar mechanical alphabet to be able to construct and understand machines: "to know all the cogs, levers, and hooks of a machine [like] a scholar [who knows] the letters of the alphabet", he stated. In short, this seems to have been Polhem's main idea for constructing the different wooden models in his alphabet.

Swedish historians of science, however, have had a hard time to figure out exactly what kind of letters (or sentences) that Polhem's alphabet actually referred to. Then again, the small models physical concreteness *and* enigmatic character did contributed to the fame of the collection. In more than one way, Polhem's alphabet is indeed "the coming into being of scientific objects", to quote Lorraine Daston. The cultural biographies of these models also display a fascinating history. First they were exhibited at the Royal Swedish Model Chamber. In 1802, however, a fire devastated parts of the collections. Most models were saved and later they were transferred to a newly established pedagogical institution of science, Teknologiska Institutet in Stockholm. Later it became Sweden's first polytechnic and prime institution of higher education in technology, and the mechanical alphabet was used as pedagogical equipment there during the whole 19th century. Eventually, the models became dated. During the 1920s, Polhem's alphabet was transferred to the Swedish National Museum of Science and Technology. Essentially, ever since his models have been exhibited as a kind of *meta-museological artifacts*. In a museological context their pedagogical quality gained a new meaning—from *actual* technological principles to *historically* situated mechanics.

At a time when heritage institutions are exploring how new digital technologies can broaden access to their collections—in a similar way that *physical models* once did—it seemed appropriate to use Polhem's alphabet and try to metamodel it in different digital formats, especially in 3D. In general, 3D heritage activities are still in their infancy—and Sweden is no exception. However, within the new interdisciplinary research project, "Digital Models. Techno-historical collections, digital humanities & narratives of industrialisation" parts of Polhem's mechanical alphabet is currently being both 3D scanned, 3D printed and 3D modelled by different software. Situated at the intersection between digitising archives and visualising history, the project—a collaboration with the Technical museum in Stockholm and the digital humanities hub, Humlab at my university—interrogates the *specificity of digitisation* with the ultimate goal of developing a methodology of high relevance for the cultural heritage sector.

If, as Fiona Cameron once argued in this great book, museum culture is perceived as series of practices for defining object value and meaning—and particularly so regarding the concepts of "material authenticity, originality, and aura"—then digitisation is (and has always) been a threat: the digital object as a "terrorist", as Cameron then alluringly put it. Writing some ten years ago, such an "apocalyptic view of the material/immaterial relationship", was according the her based on the fear that as "3D simulations become more convincing, surrogates will merge in 'form' ... viewers will [then] be unable to perceptually distinguish the replica from the real."

Traditionally, museum culture have underscored the difference in classification between originals and reproductions—with digitisation *by nature* belonging to the latter. Yet, in the case of Polhem's mechanical alphabet things gets really complicated since his models are oscillating between originals and copies—and variations thereof. Models were over centuries constantly repaired with new parts inserted in aged wooden frameworks, and today it is more or less impossible to accurately date models, let alone the chronological differences in parts. Digitising Polhem in 3D and adding these *new digital objects* to the museological politics around originals and/or copies, indeed makes matters complicated.

Following William J. Turkel, the process of digitisation creates a representation that "shares some of the attributes of an original, but not all of them." Which attributes that are transferred, displayed, and (eventually) preserved is not an "essential trait" of digitisation *per se*, only of *one* particular process (of which there can be many). To state the obvious: it is not entirely clear what it means to digitise something. The London Charter on computer-based visualisation of heritage, promotes "intellectual and technical rigour in digital heritage visualisation"—yet, in what way should one 3D digitise Polhem's models and his *Laboratorium mechanicum*? The charter recognises that the range of available computer-based visualisation methods is constantly increasing. Still, what is the exact relation between technical rigour and virtual heritage in a software culture permeated by constant updates?

In order to investigate the specificity of three-dimensional scanning, rendering and modeling—as well as to provoke a confrontation between *stupid scanning* versus *intelligent simulation*—we, that is me, museum staff and programmers at Humlab, decided to apply three forms of different 3D visualisations of Polhem's alphabet executed in altered media modalities. First of all, we used an ordinary iPhone—and the Agisoft Photoscan software—to repeatedly photograph one of Polhem's models. Secondly, we collaborated with the professional Swedish animator Rolf Lindberg who computer-animated some models (rather than scanning them). Finally, we

CT-scanned three models—that is, X-ray computed tomography —at Linköping University Hospital in a collaboration with the Center for Medical Image Science and Visualization.

On the market today, there exists a number of cheap and simple 3D apps. The Autodesk 123D Catch, for example, can generate 3D models from a number of photographs taken by basically any smart phone. However, there is no need to use a dedicated 3D application. In order to scan one of Polhem's model in the *simplest way possible*, within our project we put a copy of one model from the mechanical alphabet on a desk in the basement of the museum. In essence, we prepared nothing. We simply took an iPhone and walked around the model taking perhaps 100 hundred photographs in rapid succession with poor light conditions. The digitisation procedure, from grabbing the model from the shelf to photographing it, literally took less than a minute. The images were then loaded into Agisoft PhotoScan. Rendering a three dimensional object in PhotoScan is a procedure in different steps. First one loads and aligns the images, creating a 'point cloud' from them. Secondly, the software builds a 'dense cloud', and subsequently a 'mesh' with different textures ('shaded', 'solid' or 'wireframe'). The different executions, however, takes a substantial amount of time.

As is evident, the resulting 3D image of Polhem's model nevertheless became inadequate. We repeated the scanning procedure, but results were similar. Stupid scanning, in short, produces stupid results. Above all, deficient outcome was due to bad lightning conditions and the impossibility to really hold the iPhone steady (when walking around the model). The instability of the photographic act is in fact better compensated in various 3D apps. Still, these do not produce a computational model which one can work with (as in PhotoScan).

Our second set up in metamodeling Polhem in 3D involved a collaboration with animator Rolf Lindgren. He was invited to the museum, where he took a few photographs of three different models from the mechanical alphabet (originals and copies). His purpose of photographing the models was foremost a way to measure (and compare) them with a centimeter ruler, necessary for computational simulation. Some images were also taken of model details. Lindgren's photographs (taken by a normal digital camera) were then aligned and straightened in Photoshop before being loaded into the software Cinema 4D.

Essentially, Lindberg designed a new virtual object within Cinema 4D—loosely based on his prior photographs—where scale and details were attributes that really mattered to him. Cinema 4D lets users design objects with sophisticated 'cloner' 'lightning' and 'camera' functionalities. Hence, to reconstruct one of Polhem's models, Lindberg started with a number of geometric shapes in three dimensions (a cube, a polyhedron, a sphere etcetera). Polhem's model hence resembled a *literal model* placed onto a three dimensional spatial grid. Geometric shapes were then computationally altered and adjusted; edges were rounded, holes were cut etcetera, and different textures were afterwards applied to the model.

Metamodeling Polhem in Cinema 4D raises a number of questions regarding both accuracy in representation and authenticity vis-à-vis the original, auratic cultural heritage object. Rather than actually 3D scanning a model (an index), one might argue that the work process for animator Lindberg involved a number of *iconic steps*—that is, *likenesses*. The difficulty in rendering Polhem's models based on "technical rigour in digital heritage visualisation"—to quote the London charter again—became especially problematic regarding animations of *model movement*. Naturally, computer code could make the cogwheel, for example, to run completely smooth. In the original model, however, the cogwheel caused a lot of friction; the model was built by wood after all. We hence asked Lindberg to make friction more noticeable in his animations when the cogwheel moved. The tricky issue of *how to represent friction* in a technical rigours way in 3D, in fact, became an interesting research question for us. Since digital representations are often too good, the question from a heritage perspective essentially boils down to an issue of *interpretation*.

The issue of how to interpret friction in 3D also became apparent in our final scanning setup. Since an interactive 3D model cannot really represent movement—it then becomes a static, non-interactive animation—moving from simple scanning modes to more intelligent ones as CT-scanning, does not really solve the 'friction problem'. Nevertheless, the third way in which we scanned Polhem's model was indeed our most ambitious. In a collaboration with the company Interspectral—a visualisation software company focused on volumetric rendering and 3D digitisation—and the Center for Medical Image Science and Visualization at Linköping University Hospital, we performed a three dimensional CT-scan of five models from Polhem's alphabet.

CT-scanning is a procedure with multitudinous images taken from different angles to produce a cross-sectional and tomographic 3D image. CT-scanning hence differs from more conventional line of sight 3D scanning methods such as laser scanning and photogrammetry. In essence, CT-scanning produces virtual image slices of an object (or usually a person), allowing one to see the inside (of a body). Our idea of CT-scanning Polhem was to 3D digitise models in an undoubtedly sophisticated manner. CT-scans would allow us to see the inside of models without breaking them. It would give cues as to how they were constructed and put together. Some models are more complex mechanical wooden structures than others—and naturally, all are too fragile to take apart without destroying them.

The CT-scan was done in collaboration with the company Interspectral, and the deal was that they would deliver 3D images where we could both see inside models, and where parts of the models could also be virtually separated. The touch screen software, Inside Explorer, developed by Interspectral is designed for public use, and geared towards the heritage sector. It made it possible for us to alter between the modes of "Solid wood" or "Shell & Metal". In addition, we could rotate Polhem's models and look inside them from different angles. Nevertheless, there was in fact not much to reveal.

To conclude: as Valeria Vitale has recently argued, 3D visualisation is today a broad term used to loosely define miscellaneous computer generated three-dimensional representations of objects. In its application for cultural heritage, 3D is often divided into "'3D modeling,' which involves the use [of CAD] software … and '3D imaging,' which involves the digital recording of information on the shape and color of existing objects." The division between these two strains is, however, far from clear-cut. Different 3D techniques are usually blended, and Vitale has also stressed that a major concern with 3D is that such visualisations are opaque. It is simply difficult—if not impossible—for the public or the academic community "to assess the accuracy of the visual outcome or the soundness of the hypotheses represented" used within different modeling or scanning procedures.

As is evident from our digital 3D-interventions, scanning, rendering and modeling Christopher Polhem's *Laboratorium mechanicum* can be done in a number of ways. To the three different set ups above, we could easily have come up with a number of additional digital arrangements. We are, in fact, currently working with a fourth way to literally (re)present Polhem's mechanical alphabet by building a *virtual reality model* of the Royal Swedish Model Chamber—approximately at the time of Johann Beckmann's visit in 1765.

To sum up, using Polhem's mechanical alphabet as a case, different 3D digitisation methods will result in representations that share some attributes with the original models, but not all of them. The *specificity* of 3D digitisation depends on factors as selected materials, scanning, rendering and modeling procedures—not to mention funding. It goes without saying that the contrast between self-scanning Polhem's models and CT-scanning them is foremost one of money. The purpose, however, of these try-outs of multiple scanning procedures was to raise awareness within the heritage domain that 3D digitisation and visualisations can be done in various ways. It might not come as a surprise, and the London charter recognises a wide range of available computer-based visualisation methods. Yet it is quite another matter for a heritage institution to have the ability to *practically* test differences in 3D procedures and results.

Finally, within the heritage domain the relation between *data and object* is currently being negotiated—as far as 3D visualisations are explored. One of the major concerns regarding 3D within the heritage sector, is that without knowledge of the three dimensional scanning and/or modeling process, the public's only choice is to trust the authority of the cultural institution. Authority and material authenticity are trademarks of the heritage domain, after all. Yet, 3D visualisations will *always* cater to interpretation of museological objects, even if institutions are totally explicit and open about their digital practices.

Evidentially, when working with 3D, heritage institutions should include information about the technological set up. According to Polhem, physical models were always superior to drawings and abstract representations. But if the models within the mechanical alphabet are indeed interesting as physical traces of the material foundations of scientific knowledge, the question is if Polhem would have considered 3D visualisations in a similar manner. Who knows.