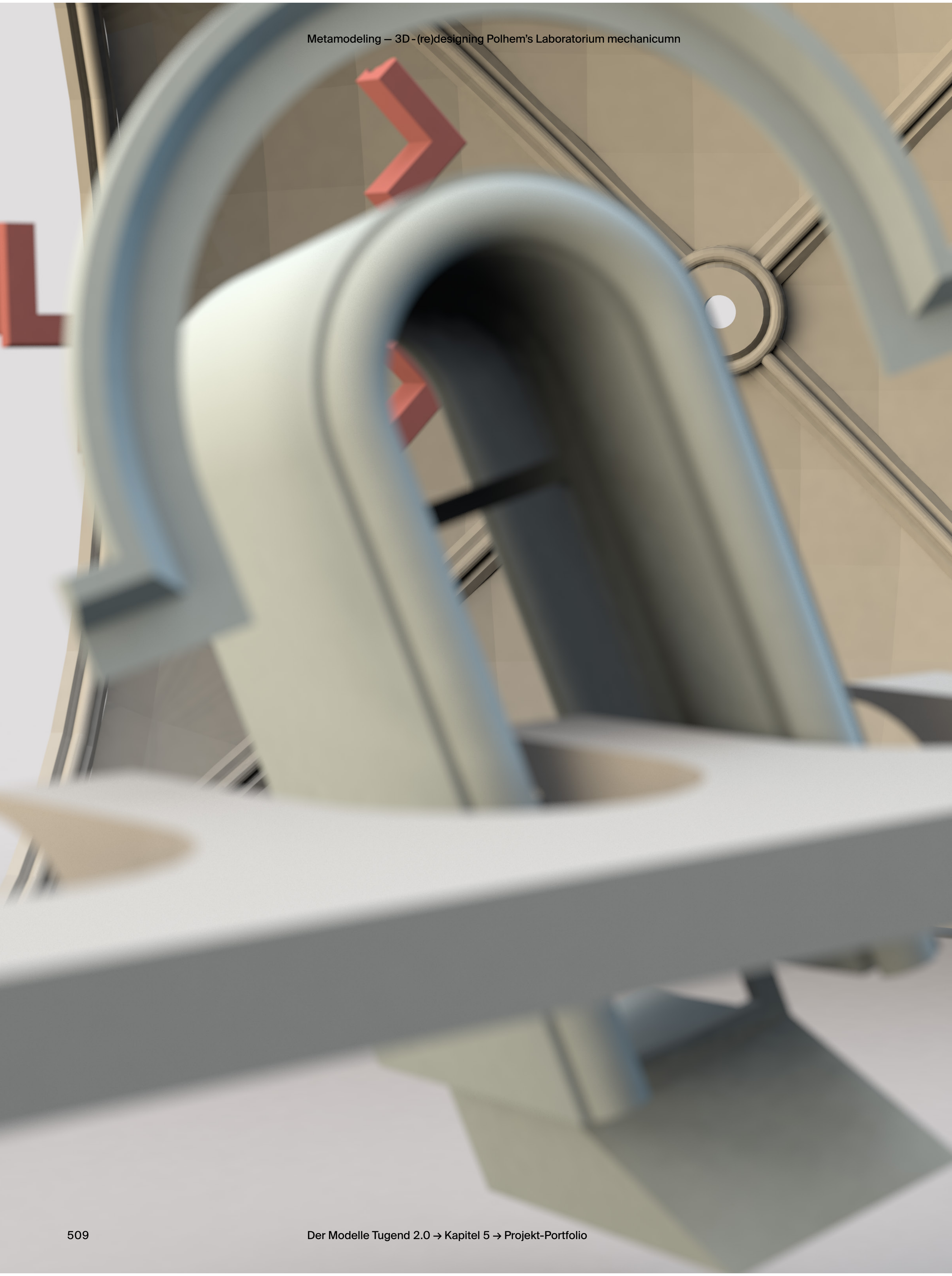


Pelle Snickars

V. Metamodeling — 3D-(re)designing Polhem's Laboratorium mechanicumn

→ 3D visualisations, digital methods, Christopher Polhem, media modalities

Based on selected parts of the collections at the Swedish National Museum of Science and Technology, the aim of the research project, Digital Models, is to explore the potential of digital technologies to reframe Swedish industrialisation and its stories about society, people and environments. This book chapter presents the work done with one model, the Swedish 18th century inventor Christopher Polhem's so called mechanical alphabet. His small wooden models were once built to pedogogically illustrate different mechanical principles. At a time when heritage institutions are exploring how new digital technologies can broaden access to their collections, the chapter recounts the ways in which our project has tried to metamodel Polhem's alphabet in different digital formats, especially in 3D. Which attributes of the models that are transferred and displayed is not an imperative trait of digitisation per se — only of one particular process. The chapter discusses three forms of 3D visualisations of Polhem's alphabet executed in altered media modalities — provoking a confrontation between stupid scanning versus intelligent simulation. Situated at the intersection between digitising archives and visualising history, the chapter interrogates the specificity of digitisation, with the ultimate goal of developing a 3D methodology of relevance for the cultural heritage domain. Authority and material authenticity are its trademarks. Yet, as this chapter will show, 3D visualisations will always cater (in one way or the other) to interpretation of museological objects selected for (re) presentation — even if institutions are totally explicit and open about their digital practises.

During the summer of 1765 a young German scholar, Johann Beckmann (1739–1811), embarked upon a trip to Sweden and Uppsala University. Beckmann was a man of enlightenment, and today he is a well-known figure within the history of science and technology. His trip to Sweden in the mid 1760s (meeting, for example, Carl Linnaeus) made a lasting impression. 01 During his trip Beckmann wrote a diary in which he described his Swedish whereabouts. A particular interest was contemporary technological improvements: **14. Sept. fuhren wir … in das berühmte Fahlun, welche Stadt nicht anders aussieht, als wenn sie die Residenz des Vulcans wäre.**

In Falun, Beckmann inspected mining techniques and machines. One water-powered mine hoist, designed by **der ehemalige Kunstmeister Rundin, ein Schüler des grossen Polhems** was particularly impressive. 02

Somewhat surprisingly, however, apart from one exception Beckmann made no further remarks to the finest and most important predecessor within the mining-invention-trade: the scientist and pre-industrial inventor, Christopher Polhem (1661–1751). Polhem had passed away some 15 years earlier when Beckmann visited Sweden. During the early 1700s Polhem had, among many things, made a number of mechanical improvements at the Falun mine, foremost revolutionary hoisting machines. In addition — at the nearby village of Stjärnsund — he had set up a preindustrial community with a semi-automated factory powered entirely by water. Polhem was a practical man, but also an original thinker on science, engineering and philosophy. 20,000 of his manuscript pages have survived, and Polhem was, for example, a great influence on Emanuel Swedenborg's later natural philosophy. For a number of years Swedenborg was, in fact, an assistant to Polhem at Stjärnsund. In Beckmann's diary, however, Polhem was only mentioned when the young German vividly described the so called, Royal Model Chamber in Stockholm.

»Die Modelkammer ist auf dem alten Schlosse und verdienet von einem jeden Liebhaber der Physik und Mathematik besehn zu werden«, Beckmann avidly stated. »Sie wurde zuerst von Polhem angelegt, dessen Maschinen doch nicht alle hier sind, weil sie im Brand verlohren gegangen.« 03

The Royal Swedish 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. Basically, 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. A royal decree from 1697 had inaugurated the **Laboratorium mechanicum**, but its history until the emergence and establishment of the Royal Model Chamber in 1756, remains obscure and hard to trace. 04

■ 01
»Ohne Zweifel sind die Anregungen, die er während seines Aufenthaltes in Upsala von Linné erhielt, für seine Lebensarbeit bestimmend geworden«, it was for example claimed in 1911 by botanist Thedor Magnus Fries in an introduction to Beckmann's travel diary — which Uppsala University published the same year as a centenary tribute Th. M. Fries (Hg.), Johann Beckmanns schwedische Reise in den Jahren 1765–1766: Tagebuch. Mit Einleitung und Anmerkungen im Auftrage der KGL. Universität Upsala, Upsala 1911. Fries is quoted from page III.

■ 02
Beckmann 1911, p. 60, 64.

■ 03
Ibid., p. 130.

■ 04
Arvid Bæckström, Kongl. Modellkammaren, in: Daedalus. Tekniska museets årsbok 1959, Stockholm 1959.

Some models of the **Laboratorium mechanicum** were located in Stockholm, others in Falun and at Stjärnsund. In fact, during Polhem's lifetime the collection of models became increasingly scattered. Around the time of his death, however, efforts were made to assemble his models in the capital to form an institution for the information and dissemination of technology [01].

TAL
OM
NYTTAN
AF ET
Laboratorium Mechanicum,
HÅLLIT FÖR
KONGL. VETENSKAPS ACADEMIEN
AF
CARL KNUTBERG,
CAPITAINE MECHANICUS,
DÅ HAN DER BLEF SÅSOM LEDAMOT INTAGEN
DEN 16 NOVEMBER 1754.

På Kongl. Vetenskaps Academiens befallning.
STOCKHOLM,
Tryckt hos LARS SALVIUS, 1754.

INVENTARIUM
ÖFVER DE
MACHINER
OCH
MODELLER,
SOM FINNAS
VID
KONGL. MODELL-KAMMAREN
I STOCKHOLM,
BELÅGEN UTI GAMLA KONGSHUSET
PÅ
K. RIDDAREHOLMEN.

STOCKHOLM,
TRYCKT HOS ANDERS J. NORDSTRÖM, 1779.

☐ 01
Book frontispieces of Carl Knutberg's, Tal om nyttan af et laboratorium mechanicum, hållit för kongl. vetenskaps academien (Stockholm, 1754), as well as the inventory (of models and machines) at the Royal Swedish Model Chamber in 1779 (compiled by Jonas Nordberg), Inventarium öfver de machiner och modeller, som finnas vid kongl. modell-kammaren i Stockholm, belägen uti gamla kongshuset på k. Riddareholmen (Stockholm, 1779).

During the latter half of the 18th century, the Royal Swedish Model Chamber [**Kongl. Modellkammaren**] was located at the fashionable Wrangels Palace on Riddarholmen in Stockholm. The institution was open to the public, and counted as one of the finest physical model collections in Europe, even a distinguished 18th century **tourist attraction.** [05] When Beckmann made his visit during the autumn of 1765, the model chamber had been in operation for a decade:

»Es ist ein sehr grosser Saal, auf welchem mehr als 100 Modelle stehn. Die mehrsten sind mechanische, einige gehören zur Experimental Physik, und einige wenige sind Modelle von Kirchen und Pallasten.« [06]

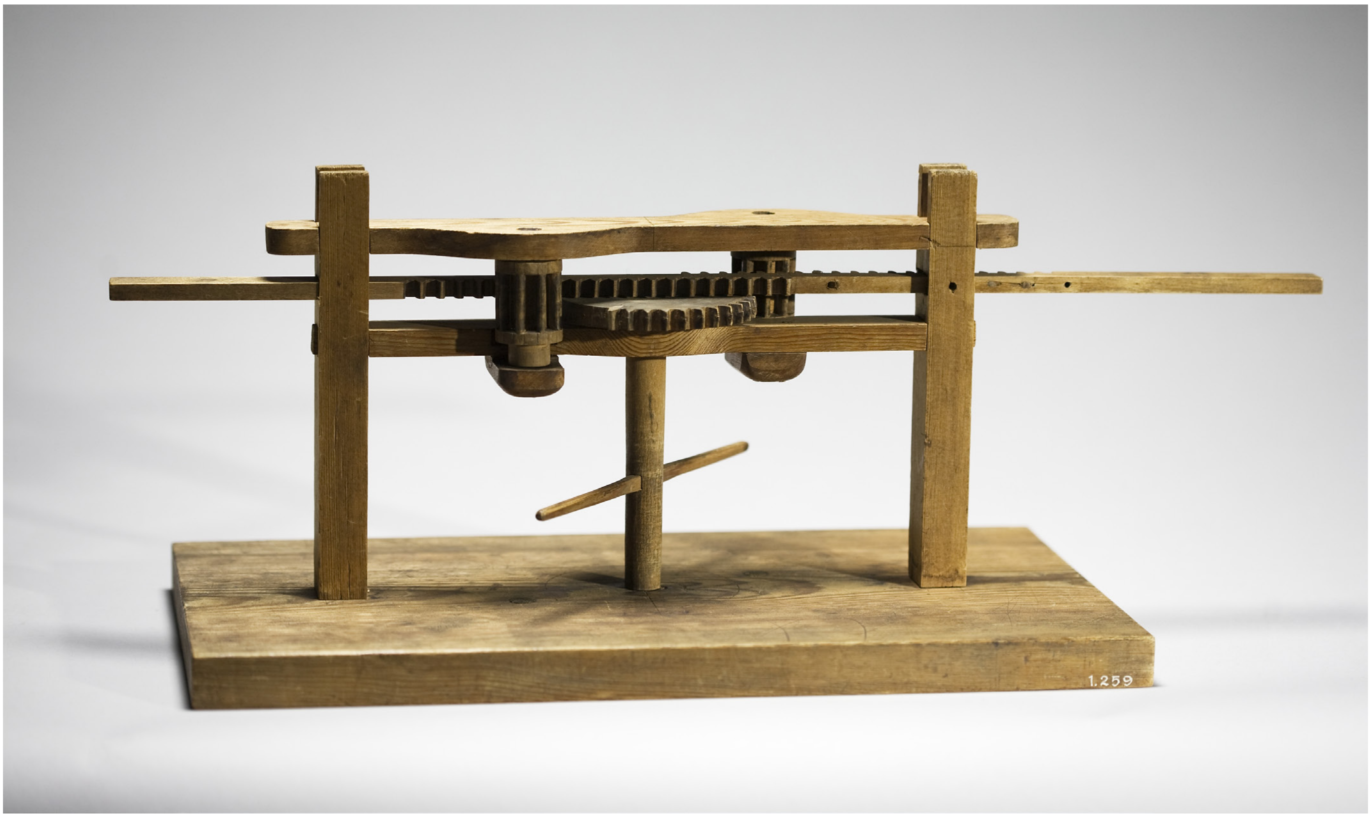
The real treasures of the model chamber was Polhem's mechanical alphabet. The small wooden models were built to illustrate different mechanical principles. Initially, it consisted of some 80 models of machine elements like the lever, the wheel and the screw, and Beckmann seems to have understood the basic ideas behind these wooden models immediately:

■ 05
Torsten Althin, Nya avdelningar Kongl. Modellkammaren, Fysikaliska experiment, Mekanisk ljudåtergivning, in: Daedalus. Tekniska museets årsbok 1947, Stockholm 1947. Around 1800 both the Spanish General Miranda and the dutch traveler Johan Meerman visited the model chamber in Stockholm: Miranda i Sverige och Norge 1787: General Francisco de Mirandas dagbok från hans resa september-december 1787, Stockholm 1950; Johan Meerman, Reise durch den Norden und Nordosten von Europa: In den Jahren 1797 bis 1800, Wien 1811.

■ 06
Beckmann 1911, 130.

»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.« 07 02.

■ 07
Ibid., p. 131.



□ 02
Models from Polhem's from the early 1700s. Actual models – whether in the form of originals or copies – can today be found at the Mining Museum in Falun as well as at the Swedish National Museum of Science and Technology in Stockholm.

V.1 Model Biography

According to Christopher Polhem, **mechanics** underpinned all knowledge: **mechanics is the foundation of all philosophy [heela philosophien]**, as he stated in one of his many unpublished manuscripts. [08] 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. It was hence as important for a mechanic

> »to know all the cogs, levers, and hooks of a machine as it was important to a scholar to know the letters of the alphabet.« [09]

This seems to have been Polhem's main idea for constructing and establishing 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. [10] Then again, the small models physical concreteness **and** enigmatic character did contributed to the fame of the collection. Hence, in more than one way, Polhem's alphabet is indeed **the coming into being of scientific objects.** [11] The cultural biographies of these models also display a fascinating history. As stated, during the second half of the 18th century Polhem's alphabet was exhibited at the Royal Swedish Model Chamber. In 1802, however, a fire devastated part of Wrangels Palace. Most models were saved and after — again — being scattered for more than two decades, they were transferred to a newly established pedagogical institution of science, **Teknologiska Institutet**. It was founded in 1827 and later changed its name to **KTH Royal Institute of Technology.** During the 19th century both the model chamber and the mechanical alphabet were used as pedagogical equipment during the establishment of KTH, Sweden's first polytechnic and prime institution of higher education in technology. However, within the interdisciplinary research project.

Eventually, all models became dated. During the 1920s, Polhem's alphabet — and other remaining artefacts from the model chamber — were consequently transferred to the newly established Swedish National Museum of Science and Technology. The museum was founded in 1924 and opened to the public in 1936. Essentially, ever since Polhem's 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. Biographies of things can make salient what might otherwise remain obscure [12], as Igor Kopytoff once famously remarked.

■ 08
Most of Christopher Polhem's manuscripts (which are notoriously hard to read and ineptly spelled) are collected at the National Library of Sweden. »Afskrift af Chr. Polhammars bref 1696 till Bergs Collegium ang. hans utländska resa och förslag till inrättandet af ett mekaniskt laboratorium«. Unpublished manuscript from the Polhem collection at the National Library of Sweden — Polhem, Christopher X 265:1.

■ 09
David Dunér, Daedalus of the North: Swedenborg's mentor Christopher Polhem, in: The New Philosophy, CXIII (3&4), 2010, pp. 1077–1098.

■ 10
The literature on Christopher Polhem is vast (but foremost published in Swedish). For an introduction — with a special emphasis on the mechanical alphabet — see for example, Sten Lindroth, Christopher Polhem och Stora Kopparberget, Uppsala 1951; William A. Johnson, Christopher Polhem, The Father of Swedish Technology, Hartford 1963; Mikael Lindgren, Christopher Polhems testamente, Stockholm 2011 and particularly, David Dunér, Tankemaskinen. Polhems huvudvärk och andra studier i tänkandets historia, Nora 2012.

■ 11
Lorraine Daston, Introduction, in: (Hg.), Lorraine Daston, Biographies of Scientific Objects, Chicago 2000, p. 1.

■ 12
Igor Kopytoff, The cultural biography of things: commoditization as process, in: (Hg.), Arjun Appadurai, The social life of things. Commodities in cultural perspective, Cambridge 1986, p. 67.

After a longer period of restoration, a dedicated exhibition centered around Polhem's mechanical alphabet and the Royal Model Chamber opened at the National Museum of Science and Technology in 1947. During the late 1960s the exhibition was reorganised and from the late 1990s and onwards 30 models have been on permanent display. The mechanical alphabet fitted neatly in different museological exhibition contexts — both in Stockholm and at the Mining Museum in Falun (where some models were also located). The models were small and displayable, and could easily be framed as pedagogical museological objects **avant la lettre.** Without exaggeration, the cultural-historical and pedagogical significance of Polhem's mechanical alphabet has been of great important for the Swedish National Museum of Science and Technology as **a prime model collection** concerning the history of technology and science — both as a pedagogical tool and as a way of displaying and visualising principles of technology.

V.2 Digital Models

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** did before — it seemed appropriate to use Polhem's alphabet and try to metamodel it in different digital formats, especially in 3D. As is well known, the technologies

> »needed to digitize, publish, and print cultural heritage resources in three dimensions (3D) are increasingly within reach of memory institutions.« [13]

■ 13
Richard Urban, Collections Cubed: Into the third dimension, http://mw2016.museumsandtheweb.com/paper/collections-cubed-into-the-third-dimension/.

3D formats of physical models (in both virtual and 3D print) can be used to give new access, preserve and eventually even **play with** archival collections. As Valeria Vitale has argued, 3D visualisation is today a broad term used to loosely define miscellaneous computer generated threedimensional representations of objects. In its application for cultural heritage, 3D is often »divided into ›3D modeling‹, which involves the use of Computer Aided Design (CAD) software and the creation of 3D content from scratch, and ›3D imaging‹, which involves the digital recording of information on the shape and colour of existing objects.« [13] 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 completely ›opaque‹«. [13]

It is simply difficult — if not impossible — for audiences, the public or the academic community »to assess the accuracy of the visual outcome or the soundness of the hypotheses represented« [14] used within different modeling or scaning procedures.

■ 14
Valeria Vitale, Transparent, Multivocal, Crossdisciplinary: The Use of Linked Open Data and a Community-developed RDF Ontology to Document and Enrich 3D Visualisation for Cultural Heritage, in: Gabriel Bodard (Eds.) & Matteo Romanello, Digital Classics Outside the Echo-Chamber: Teaching, Knowledge Exchange & Public Engagement, London 2016, p. 148.

In general, 3D heritage activities are still in their infancy — and the same goes for Swedish memory institutions. 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. Based on selected parts of the Swedish National Museum of Science and Technology's collections, the project aim is to explore the potential of digital technologies to reframe Swedish industrialisation and its stories about society, people and environments. Situated at the intersection between digitising archives and visualising history, the project in short interrogates the **specificity of digitisation** — with the ultimate goal of developing a methodology of high relevance for the cultural heritage sector. [15]

If, as Fiona Cameron once argued, 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 alluringly put it. Such an **apocalyptic view of the material / immaterial relationship** was according the her (writing some ten years ago) based on the fear

> »that as 3D simulations become more convincing, surrogates will merge in ›form‹ ... with the physical object, and viewers will be unable to perceptually distinguish the replica from the real. Collections could then become obsolete, thus undermining museum culture and practice.« [16]

Traditionally, museum culture have also 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 get 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 even more complicated. Then again, the **double movement from object to data, and from data to object** is a fundamental (and philosophical) question that today haunts not only the heritage domain. Following Yuk Hui and arguments in his book, **On the Existence of Digital Objects**, the same relation between objects and data will all likely be an ongoing project

> »that will continue to develop over the coming decades. It presents us with new forms of objects, constituting a new milieu in need of further reflection.« [17]

■ 15
The project »Digital Models« is a collaboration between the Swedish National Museum of Science and Technology, with a national responsibility for technical and industrial heritage, and the digital humanities hub, Humlab at Umeå University. It is headed by the author of this book chapter, and involves three researchers, two programmers and four museum staff members. The project is funded by approximately one million euro by the Royal Swedish Academy of Letters, History and Antiquities, and runs between 2016 and 2019. For more information — http://digitalamodeller.se/in-english/.

■ 16
Fiona Cameron, Beyond the Cult of the Replicant: Museums and Historical Digital Objects — Traditional Concerns, New Discourses, in: (Hg.) Fiona Cameron & Sarah Kenderdine, Theorizing Digital Cultural Heritage. A Critical Discourse, MIT Press, 2007, p. 51.

■ 17
Yuk Hui, On the Existence of Digital Objects, Minneapolis 2016, p. 52.

He is all likely right, and the research project **Digital Models** departs from the fact that the process of digitisation creates a representation **that shares some of the attributes of an original**, to quote William J. Turkel — but as he also states: **not all of them.** Which attributes that are transferred, displayed, and (eventually) preserved is not an **essential trait** [18] of digitisation **per se**, only of **one** particular process (of which there can be many). The potential **circulation** back and forth between the digital and the object should hence be seen as an integrated part of the digitisation process:

■ 18
William J. Turkel, Hacking history, from analogue to digital and back again, in: Rethinking History 15 (2), 2011, pp. 299–312.

»what can be converted from analogue to digital can always be converted back into various analogue forms. These processes of materialization complement processes of digitization.« [19]

■ 19
Turkel 2011. For a further discussion around relational models between the analogue and the digital, see William J. Turkel & Devon Elliott, Making and Playing with Models: Using Rapid Prototyping to Explore the History and Technology of Stage Magic, in: (Hg.) Kevin B. Kee, Pastplay: Teaching and Learning History with Technology, Ann Arbor 2014.

It might sound banal, but digitisation is consistently related to various forms of materialisation; procedures are reciprocal and digitisation / materialisation can be executed in many different ways — especially regarding 3D. Arguably, best practise within the heritage domain today differs substantially. Consequently, the research project **Digital Models** uses and perceives digitisation as a **diversified activity**, with results that vary depending on hardware, software and infrastructural set-up. The latter is especially important, and as Zack Lischer-Katz has argued, discourses on the **immateriality of digital information** have during the last decade slowly given way to a rethinking of digital materiality as

»media archives are increasingly converting their collections into digital form, stored less and less on shelves in climate-controlled vaults, and instead stored and accessed through data servers.« [20]

■ 20
Zack Lischer-Katz, Studying the materiality of media archives in the age of digitization: Forensics, infrastructures and ecologies First Monday 22(1–2), 2017, http://www.firstmonday.org/ojs/index.php/fm/article/view/7263.

Another point of departure for our project is hence that digital archives are more **invisible** than traditional archives, since the mechanisms regulating them are virtually hidden behind a graphical user interface (which obviously is in conflict with historical methodologies emphasising source criticism). 3D digitisation (whether in the form of scanning, rendering or modeling) is no exception. Moreover, what is regularly forgotten when theorising the digital transfer of archives and museological collections is that the infrastructures that harness digitisation activities are usually conditioned by **concrete and mundane matters** like outsourced entrepreneurial enterprises and companies — who in our project does the practical digitisation work — price charged, speed of deliverance etcetera. Digitisation is hence **also** a commercial service.

V.3 Modeling Polhem

It is to state the obvious that material selected for digitisation will affect outcome and results. Our research project, **Digital Models**, is therefore conceptually arranged around the digitisation of **three different categories** of materials that in altering ways mirror three phases of industrialisation. [21] This book chapter, however, is solely concerned with Polhem's models — and only 3D digitisation of them, not 3D print. Evidently the chapter is related to an increased academic interest around the **material conditions** of historical knowledge production, research and education — as well as the ramifications of digitisation. 18th century physical models as Polhem's mechanical alphabet (and the often sophisticated craft involved in constructing them), testifies for instance to the historical **use of scale** — i. e. letting the large be represented by the small — and the idea that **the same laws apply to both.** It is something we take for granted today, **but this was far from obvious for the contemporaries of Polhem.** [22] Paramount, however, these types of historical objects should be understood in relation to the different scientific and didactic **practices** in which they were used. As has been convincingly argued in the edited collection, **Das materielle Modell**, the physical appearances of models are simply secondary to their usage:

> »Materielle Modelle sind nicht durch physische Merkmale zu definieren und von anderen wissenschaftlichen Objekten zu unterscheiden. Vielmehr teilen materielle Modelle Funktionen in der wissenschaftlichen Praxis. Ein materielles Objekt ist genau dann ein materielles Modell, wenn es als Modell verwendet wird. Materielle Modelle lassen sich somit nur verstehen, wenn sie durch ihre Anwendungen betrachtet werden.« [23]

It is not always entirely clear what it means to digitise something. The project **Digital Models** on the one hand makes a general analyses of the specificity of digitisation (via three different collections of materials). On the other hand, the project also address the challenges of digitising disparate forms of data and visualisations in immersive, virtual reality environments. Following the London Charter on computer-based visualisation of heritage, it 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 London Charter defines principles for the use of computer-based visualisation methods **in relation to intellectual integrity, reliability, documentation, sustainability and access.** Indeed, 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? [24]

■ 21
The different materials are: (A.) parts of the business leader and industry historian Carl Sahlin's extensive collection. (B.), all editions of the museum yearbook, Daedalus (1931–2017), and (C.) physical models from Polhem's mechanical alphabet. Following the project set-up, these different heritage materials and industrialisation phases correspond to three methodological approaches: traditional digitisation (A.), mass digitisation (B.) and 3D digitisation (C.). Digitisation methods are hence correlated with different industrial-historical periods, and in effect will result in three sets of digital tools and applications focused on various narratives of Swedish industrialisation.

■ 22
Philip Gerlee & Torbjörn Lundh, Scientific Models. Red Atoms, White Lies and Black Boxes in a Yellow Book, Cham 2016, p. 25.

■ 23
David Ludwig, Cornelia Weber, Oliver Zausig (Hg.), Das materielle Modell. Objektgeschiten aus der wissenschaftlichen Praxis, Paderborn 2014, p. 13.

■ 24
The London Charter for the Computer-Based Visualisation of Cultural Heritage, http://www.londoncharter.org/fileadmin/templates/main/docs/london_charter_2_1_en.pdf, p. 4, 2.

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 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.

V.4 Generating 3D Models from Photographs

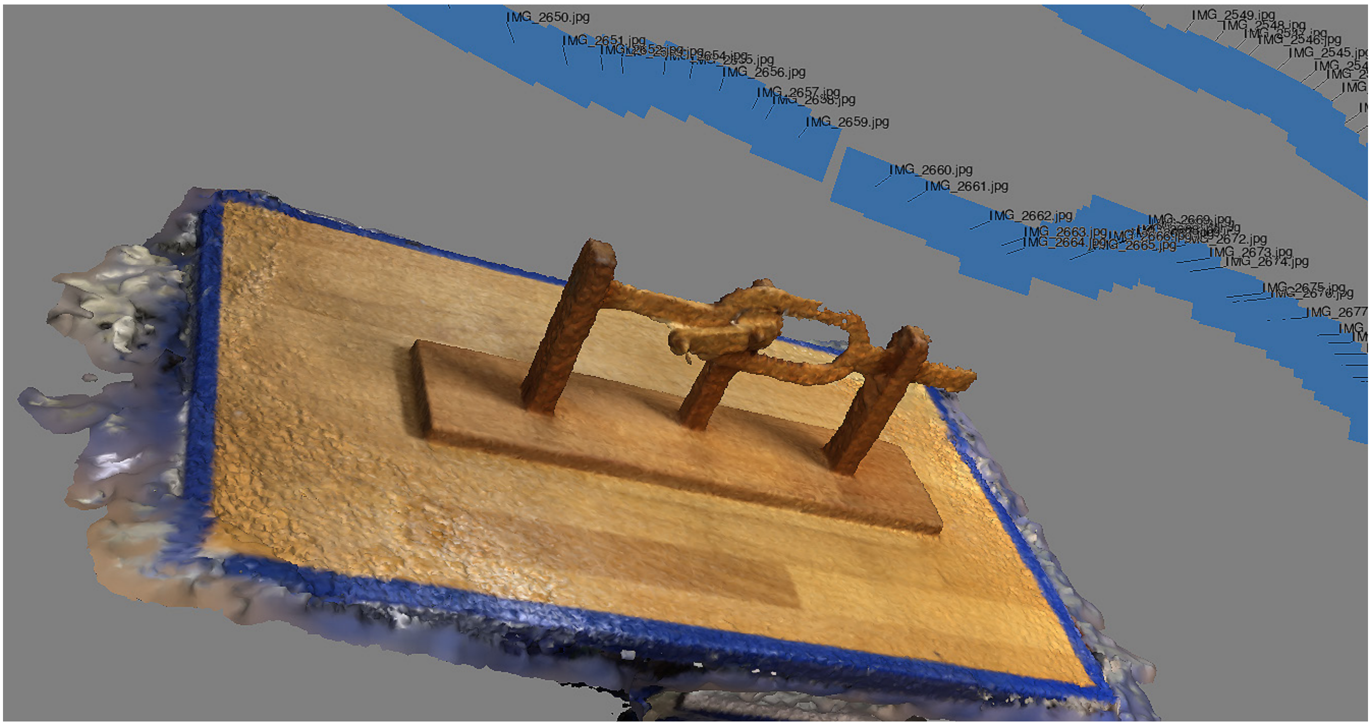
On the market today there exists a number of cheap and simple 3D apps. The Autodesk 123D Catch, for example, can generate 3D models from a number of photographs taken by basically any smart phone; it **lets you create 3D scans of virtually any object.** [25] The basic principle is that one walks around an object taking successive photographs, and then the software combines them into a three dimensional representation. Even if the commercial slogan to **turn ordinary photos into extraordinary 3D models** is exaggerated, apps like Autodesk 123D Catch (and the like) do a decent job in rendering three-dimensional representations, and especially so if the objects are not too detailed, lightning conditions are good and the smartphone has a decent camera.

However, there is in fact 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 Swedish National Museum of Science and Technology. In essence, we prepared nothing (and thus mimicked the behaviour of a normal museum visitor). 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, a software that **performs photogrammetric processing of digital images and generates 3D spatial data.** A free 30-day trial is available online (but we used a pirated pro version). Agisoft PhotoScan does indeed produce quality and accurate results, and online it is explicitly stated that the digital photogrammetry technique can be used **in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales.** [26]

■ 25
Autodesk 123D Catch, http://www.123dapp.com/catch.

■ 26
Agisoft PhotoScan, http://www.agisoft.com.

Rendering a three dimensional object in Agisoft 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 takes a substantial amount of time, however. The computer (we used a standard MacBook Air) had to work for a few hours in order to produce a computational model, in which we were able to zoom in and out, rotate, show camera angles etcetera. 03



☐ 03
Simple scanning of one wooden model from Polhem's mechanical alphabet — using an iPhone and the software Agisoft Photoscan. The IMG.jpg-markers indicate where photographs were taken.

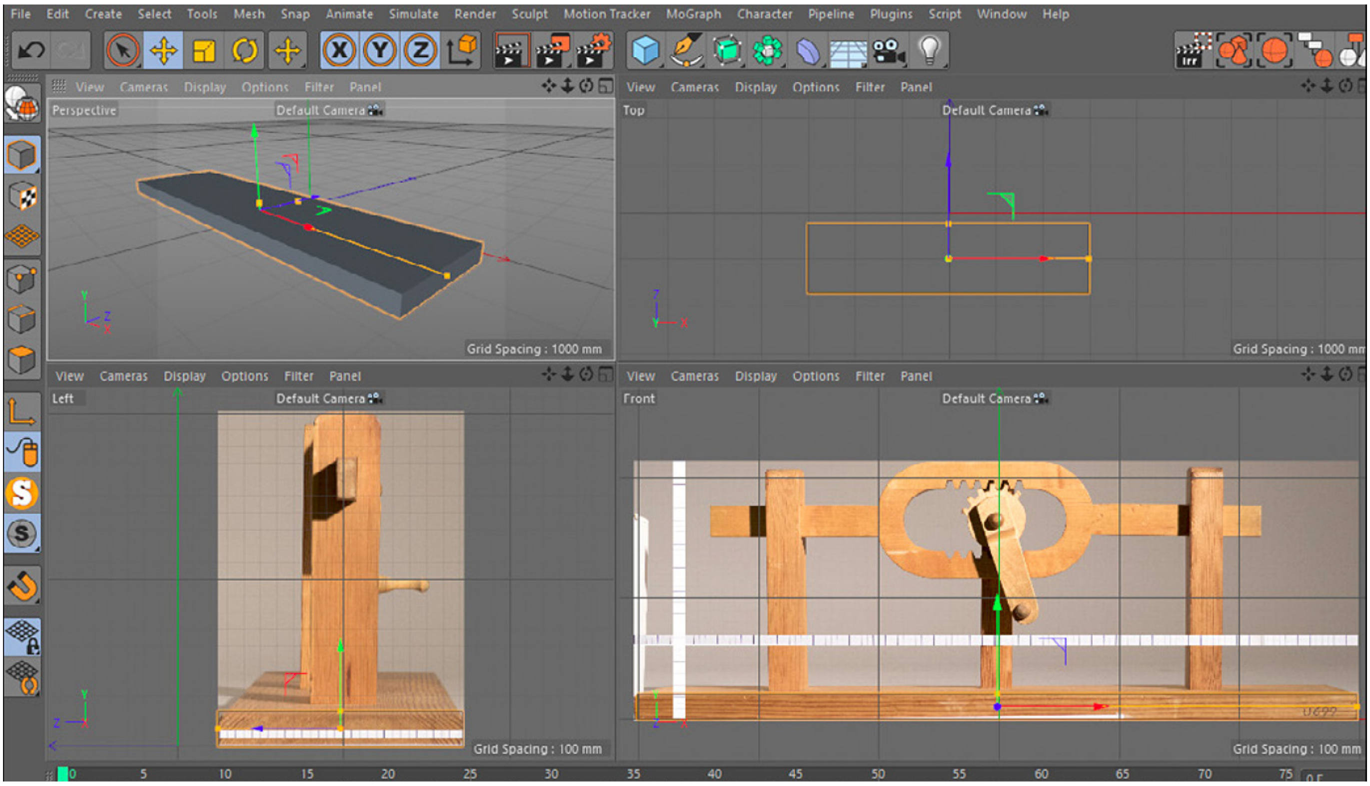
As is evident from the illustration, the resulting 3D image of Polhem's model nevertheless became inadequate. We repeated the scanning procedure, but results were similar. Stupid scanning, in short, produces stupid results. Above all, deficient outcome was due to bad lightning conditions and the impossibility 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). We also made an experiment, photographing one of Polhem's model at the Mining Museum in Falun through a glass display (the model was placed on a rotating plate). Circumstances thus resembled that of a regular visitor (trying to make a 3D copy). Agisoft PhotoScan was able to process the poor images — albeit with a reconstruction time of 61 hours.

V.5 Computer-Animated Models

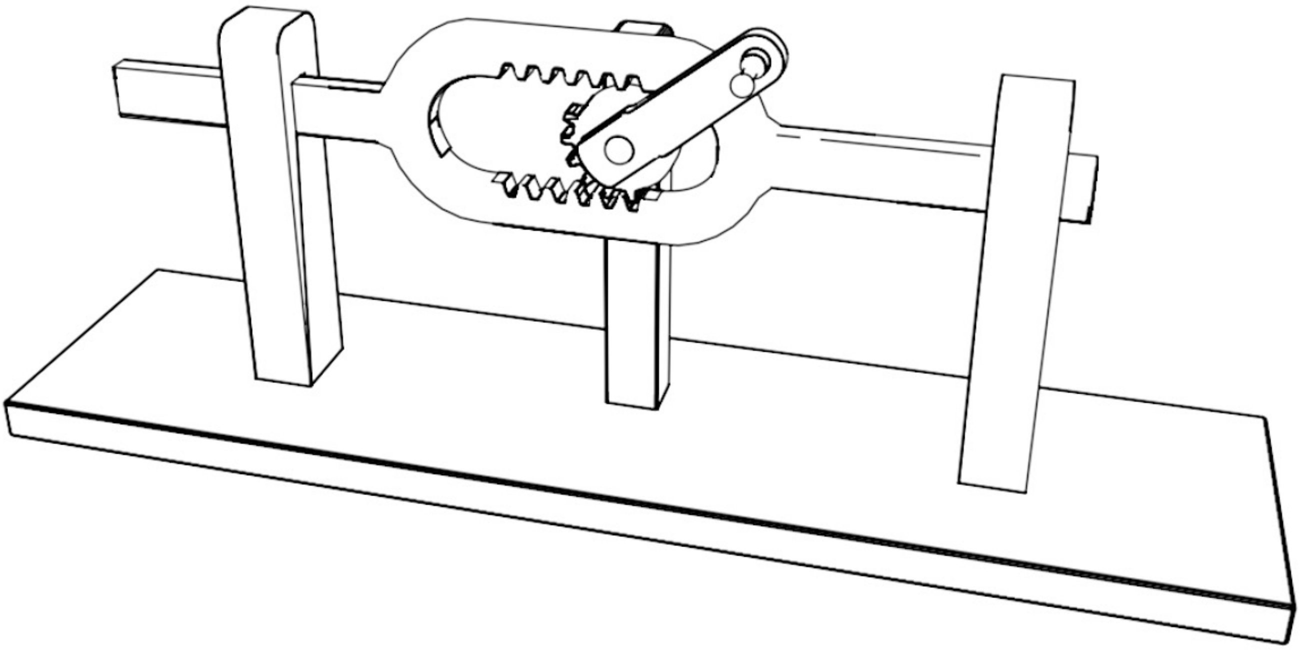
Our second set up in metamodeling Polhem in 3D involved a collaboration with animator Rolf Lindgren. He was invited to the museum, where he took a few photographs of three different models from the mechanical alphabet (originals and copies). His purpose of photographing the models was foremost a way 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, a professional 3D package. 04 27

■ 27
On the software Cinema 4D, https://www.maxon.net/en/.

☐ 04
In a project collaboration with animator Rolf Lindberg, he simulated a model from Polhem's mechanical alphabet — by way of a few photographs — and constructed a brand new virtual object in 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 (or in this case redesign) 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). As is evident from 04, initially, Polhem's model hence resembled a **literal model** placed onto a three dimensional spatial grid. Geometric shapes were then computationally altered and adjusted; i. e. edges were rounded, holes were cut, new shapes inserted, a cogwheel cut out from a spheric shape etcetera. Different textures were afterwards applied to the model, including shadows to accentuate depth. The are a number of default textures in Cinema 4D; and naturally different ones for wood as well. A software algorithm can also imitate wooden textures from a photograph. Finally, Lindberg used the camera functionality within the software to record model rotation, making a video from different angles, including zooming in and out of details. 05



☐ 05
Simulating Polhem in Cinema 4D step by step — from a rudimentary three dimensional drawing to a detailed cogwheel with wooden textures.

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 result was a 3D model, which Lindberg also displayed as a two-dimensional animation (i. e. 3D rendering). In one way, Lindberg hence reversed the representational process, since the original object (Polhem's model) was reduced to a kind of image replica he only needed a few photos for the new virtual model he constructed.

The difficulty in rendering Polhem's models based on **technical rigour in digital heritage visualisation** [28] — to quote the London charter again — became especially problematic regarding animations of **model movement.** Naturally, computer code could make the cogwheel (in the model above) run completely smooth. In the original model, however, the cogwheel caused a lot of friction; the model was made of wood after all. We hence asked Lindberg to make friction more noticeable in his animations when the cogwheel moved (which he did). In fact, the tricky issue of **how to represent friction** in a technical rigours way in 3D, became an interesting research question for us. As is often the case, digital representations are often too good. The problem is common in the heritage domain; how to deal with and think about the exact representation of color, for example, when digitising older photographs or films? Lindberg has, in fact, prior worked with the Swedish Film Institute in restoring silent films and animated intertitles, and often argued that his textual animations were inappropriate in relation to the original print. How stained and smudge should an original silent cinema intertile actually look like? From a heritage perspective the question always comes down to **interpretation.** In a similar manner, friction in relation to movement in Polhem's models also became a question of interpretation, even if (in this case) we could actually look at the original models and see how they behaved friction wise when the cogwheel was turned.

■ 28
The London Charter 2009, p. 4.

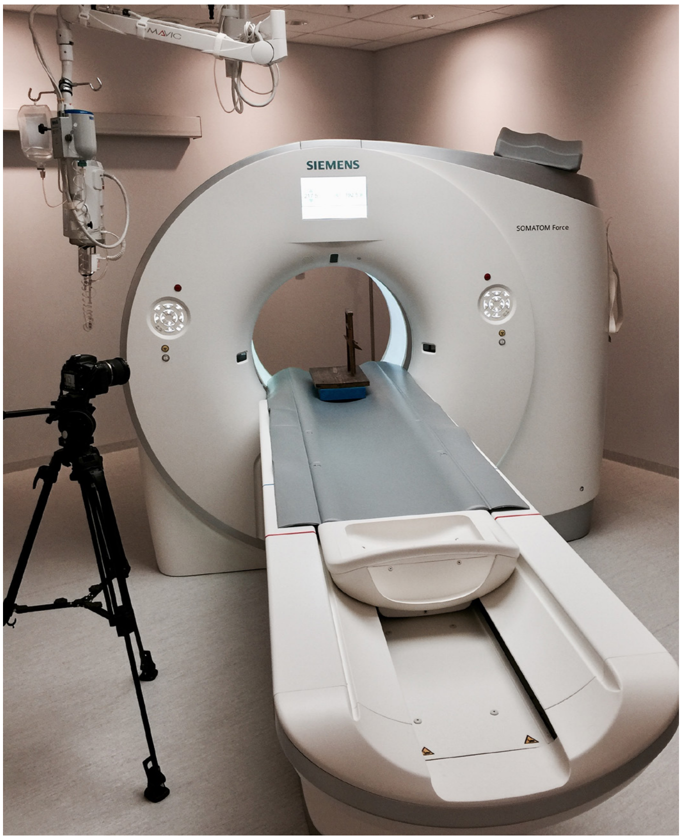
V.6 CT-Scanning Models

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 (i. e. 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 (CMIV) at Linköping University Hospital, we performed a three dimensional CT-scan of five models from Polhem's alphabet. CMIV conducts

> »focused front-line research within multidisciplinary projects providing solutions to tomorrow's clinical issues.« 29

■ 29
For further information around the Center for Medical Image Science and Visualization (CMIV) at Jönköping University, https://www.liu.se/?l=en&-sc=true.

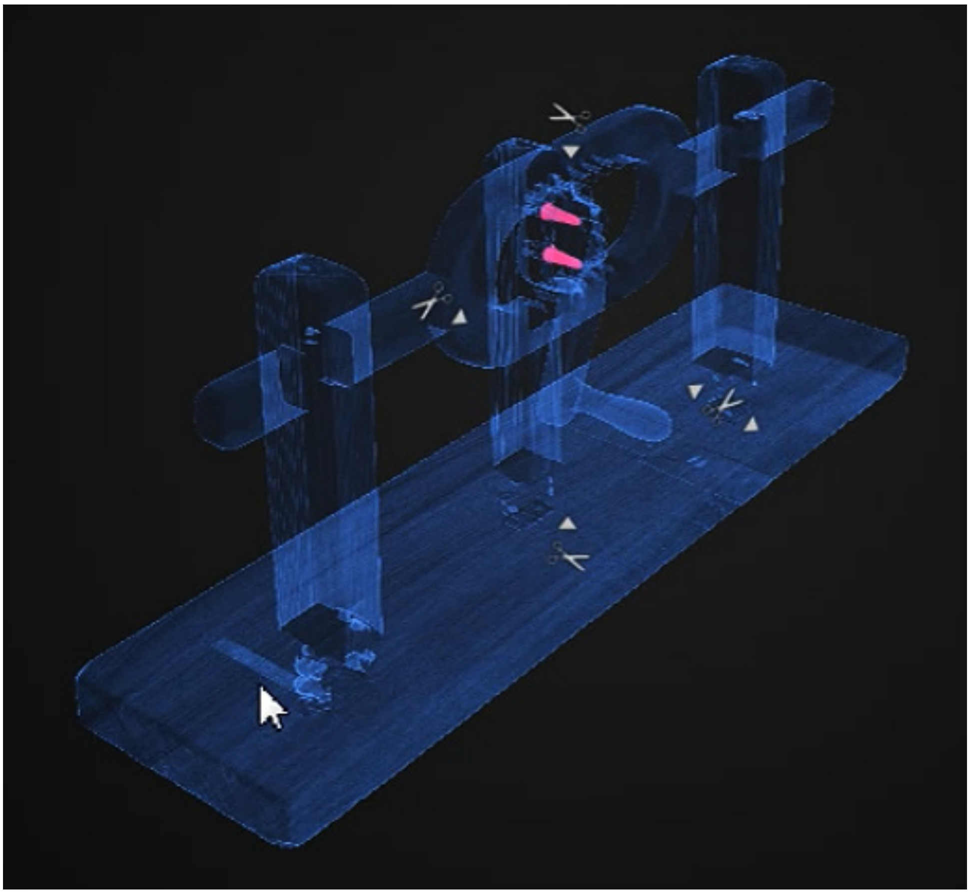
Some projects have a slant of medical humanities to them, but basically CMIV's mission is to develop methods (and tools) for image analysis and visualisation within healthcare and medical research. Scanning old wooden models from a pre-industrial inventor was, hence, an exception — even to the extent that the U. S. History Channel was present the day we scanned our models (shooting footage for a forthcoming documentary on new technological ways of analysing objects from the past). 06



□ 06
CT-scanning a model from Polhem's mechanical alphabet at the the Center for Medical Image Science and Visualization (CMIV) at Linköping University Hospital.

As one of few medical image centers in the world, CMIV has a state of the art Siemens CT Force scanner. It produces extreme high resolution images, making it possible for example to monitor blood flows. 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). The scanner which we loaded Polhem's models onto, is actually regularly used within medical forensics and criminal investigations at the Linköping University Hospital to locate bullets in victims.

Basically, our idea of CT-scanning Polhem was to 3D digitise models in an undoubtedly sophisticated manner. In addition, 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. CT-scanning, however, has nothing to due with chronological issues, i. e. trying to date models. Moreover, 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. We were hence able to look inside five of Polhem's models through the software Inside Explorer. 07



☐ 07
Inside Polhem — CT-scanning a model in collaboration with the company Interspectral made it possible to see inside models without breaking them.

Inside Explorer is a touch screen software developed by Interspectral that enables

»users to explore objects that have been scanned with 3D x-ray. Using touch gestures users can examine complex 3D data in an intuitive and exciting way.« [30]

The software is designed for public use, and interestingly geared towards the heritage sector. Interspectral has, for example, collaborated with the the Dutch National Museum of Antiquities and 3D scanned a three-metre-long mummified Egyptian crocodile which the Inside Explorer software lets users peek inside. [31] The same software 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 — apart from a few screws and differences in wooden density. Arguably, a mummified crocodile potentially unveils more astonishing things than old wooden models.

■ 30
For information about Interspectral's software Inside Explorer, http://www.interspectral.com/inside-explorer/.

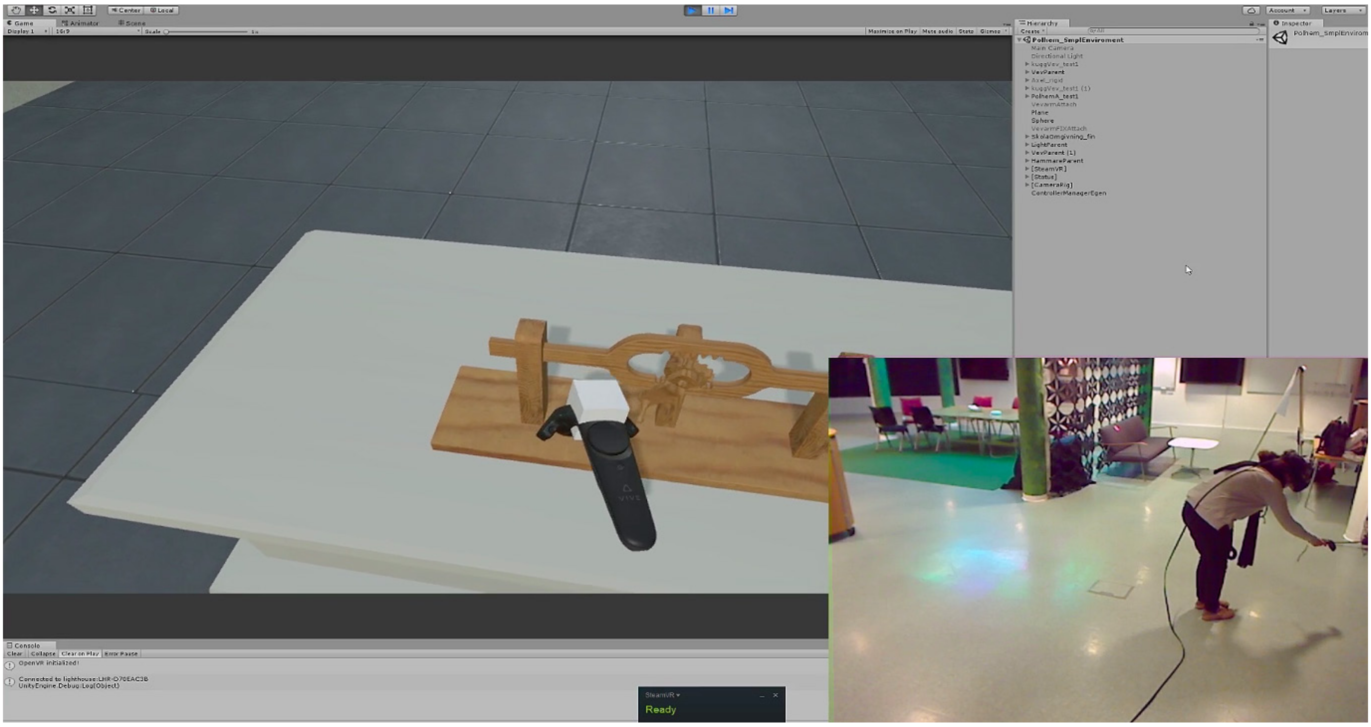
■ 31
For further information on the mummified Egyptian crocodile, http://www.interspectral.com/projects/rmo/.

V.7 Concluding Remarks

As is evident from the digital interventions and short empirical descriptions in this book chapter, scanning, rendering and modeling (parts of) 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. Within the project **Digital Models** we have also worked 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. 08

Through the usage of HTC Vive glasses — and the software Unity — we have virtually metamodeled how the Royal Swedish Model Chamber looked like in the mid 1760s. The task, however, has proven to be somewhat difficult since there are no known illustrations or archival documents as to what the interior of the model chamber actually looked like. Nevertheless, the purpose is on the one hand to increase historical understanding about the the model chamber and Polhem's models via visualisation and virtualisation, as well as to examine and investigate the potential of VR-technology in rendering a distinct historical place and time (i. e. look, feel, touch and sound). On the other hand our idea is to examine different forms of interactivity by inserting a number of Polhem's models in the virtual model environment, and hence experiment with novel ways to use the pedagogical quality of his models.

☐ 08
Remodeling Johann Beckmann's 1765 visit to the Royal Swedish Model Chamber — in virtual reality.



To sum up, using Polhem's mechanical alphabet as a case, this book chapter has shown how differences in 3D digitisation 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, software and hardware — not to mention funding. It goes without saying that the contrast between self-scanning Polhem's models and CT-scanning them at a university hospital is foremost one of money. The purpose, however, of these try-outs of multiple scanning procedures within our project has been 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 naturally the London charter recognises a wide range of available computer-based visualisation methods. Yet it is quite another matter for a heritage institution as the Swedish National Museum of Science and Technology to have the ability to **practically** test differences in 3D procedures and results.

Finally, within the contemporary heritage domain one might argue that the relation between **data and object** is currently being negotiated (and perhaps also renegotiated). At least the claim can be made as far as 3D visualisations are explored. One of the major concerns, however, regarding 3D within the heritage sector, is that without knowledge of the three dimensional scanning and / or modeling process, and not

»knowing enough about the process of building both the 3D visualisation and its interpretation, the public's only choice is to trust the authority of the cultural institution.« [32]

■ **32**
Vitale 2016, P. 149.

Authority and material authenticity are trademarks of the heritage domain. Yet, as this book chapter has shown, 3D visualisations will **always** cater (in one way or the other) to interpretation of museological objects selected for representation — even if institutions are totally explicit and open about their digital practises. Evidentially, when working with 3D, heritage institutions should be attentive to, and include information about the technological set up.

Suffice to say, one should — last but not least — also acknowledge that 3D appearances of Polhem's models will on nearly all occasions be secondary to their actual historical usage. Following Polhem, physical models were always superior to drawings and abstract representations. But if the models within the mechanical alphabet are 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. Within the project **Digital Models** we would like to think that he would have approved.