DEEP TIME OF THE MUSEUM / The Materiality of Media Infrastructures

Aalto-yliopisto

Samir Bhowmik

1. Light is History Installation at Hakaniemi Market Square, November 2012. Photo: Kukka Suonio

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Samir Bhowmik
Helsinki
16.10.2016

LIST OF ABBREVIATIONS

AMI	Advanced Metering Infrastructure
API	Application Programming Interface
BIM	Building Information Model
CAFM	Computer Aided Facility Management
CHSDM	Cooper Hewitt Smithsonian Design Museum
CIS	Contact Image Sensor
CMS	Collections Management System
CNC	Computer Numerical Control
CPU	Central Processing Unit
DAM	Digital Asset Management
DIY	Do it Yourself
GJ	Gigajoule
GUI	Graphical User Interface
HVAC	Heating, Ventilation and Air Conditioning
ICT	Information and Communications Technology
IDE	Integrated Development Environment
JSON	JavaScript Object Notation
KWH	Kilowatt Hour
LAD	Lamp Artifact Display
LCD	Liquid-crystal Display
LED	Light Emitting Diode
MWH	Megawatt-hour
NFC	Near Field Communication
OCR	Optical Character Recognition
OLED	Organic Light-emitting Diode
RAID	Redundant Array of Independent Disks
RH	Relative Humidity
SMD	Surface Mounted Device
SQL	Structured Query Language
TMS	The Museum System
TUI	Tangible User Interface
XML	Extensible Markup Language

1

INTRODUCTION

1.1 INTRODUCTION TO MUSEUM INFRASTRUCTURE

> *"they are everywhere and nowhere, at once….these dynamics of appearance and disappearance, of visibility and invisibility are perhaps somewhat fundamental to what is to be technological."*[1]

Jamie Allen says that infrastructures are at once easily detected and indiscernible — and, according to Star and Ruhleder, people commonly envision infrastructure as "a system of substrates-railroad lines, pipes and plumbing, electrical power plants, and wires" that is by definition invisible, part of the background for other kinds of work.[2] "This image holds up well enough for many purposes - turn on the faucet for a drink of water and you use a vast infrastructure of plumbing and water regulation without usually thinking much about it"[3]

According to Larkin, – "infrastructures are built networks that facilitate the flow of goods, people, or ideas and allow for their exchange over space. As physical forms they shape the nature of a network, the speed and direction of its movement, its temporalities, and its vulnerability to breakdown. They comprise the architecture for circulation, literally providing the undergirding of modern societies, and they generate the ambient environment of everyday life."[4] Generally, infrastructure usually refers to fundamental national technical systems and facilities serving population centers that include electricity, water, sanitation, telecommunication, bridges and roads. Bowker says that the term "infrastructure" evokes vast sets of collective equipment necessary to human activities, such as buildings, roads, bridges, rail tracks, channels, ports, and communications networks. It also refers to national institutions that are necessary for a nation or city to function. Appropriate infrastructure is essential for enabling, sustaining and enhancing societal living standards. But, "beyond bricks, mortar, pipes or wires, infrastructure also encompasses more abstract entities, such as protocols (human and computer), standards, and memory."[5] This infrastructure typically exists in the background, it is invisible, and it is frequently taken for granted.[6]

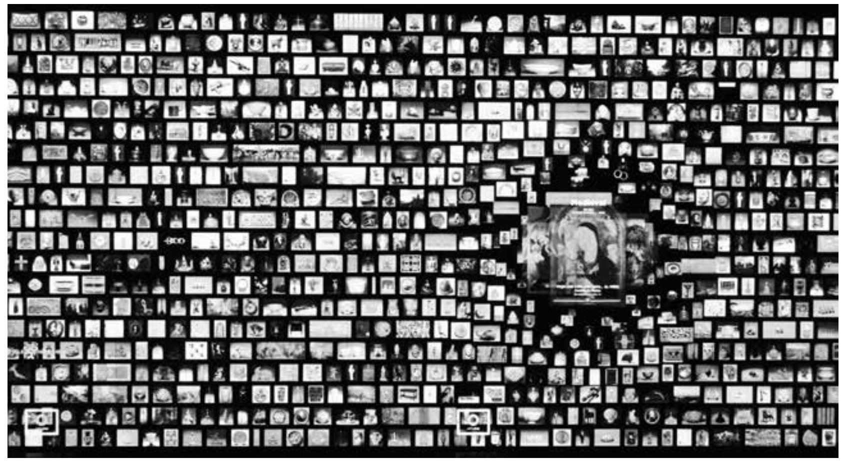


Fig. 1.1. The Collection Wall at Gallery One, Cleveland Museum of Art. The wall is composed of 150 MicroTiles and displays more than 23 million pixels equivalent of more than twenty-three 720p HDTVs.[7] Photograph by Erik Drost, distributed under a CC BY 2.0 license. Image downloaded from http://www.clevelandart.org/gallery-one/collection-wall in March 2016.

The museum as an institution can also be considered as an infrastructure. It is in fact composed of a media infrastructure that is an intricate content-generating and distributing entity hard to categorize into a single field just as "infrastructure in itself is usually difficult to visualize in its entirety within a single frame."[8] The museum is situated upon a complex and historical body of invisible materiality that not only includes the architecture and mechanical systems but also computer hardware, software technologies and operations. Parks calls this the bricks and mortar, the physical networks of digital media distribution, the 'stuff you can kick'[9] These together work in synchronization to safeguard collections, exhibit and present cultural experiences.

A museum visitor is barely aware of the invisible infrastructure that supports her engagement with the museum's collections, or a remote museum audience hardly registers the vast internet and energy-intensive cloud computing infrastructure that operates in the browsin of digital artifacts.[10] By focusing on cultural content, without understanding the powering and preservation of the material media, we are likely to miss the critical aspects of open access to knowledge and the power of institutions as major culture distribution systems. Kittler says that what remains of people is what media can store and communicate - what counts are not the messages or the content with which they equip so-called souls for the duration of a technological era, but rather their circuits, the very schematism of perceptibility.[11]

According to Allen, infrastructures and institutions are related: they are conjoined twins—the former generally thought to be the latter's more obstinate, material counterpart. The practices of institutions create and sustain infrastructures, and, reciprocally, institutions require the channels and stratifications scaffolded by them.[12] Thus, the Museum is not only the object (infrastructure that operates) and also the subject (author of operations). The Museum is not only is a carrier of culture (collections) but in itself is an archive of cultural engineering, by its very material fabrication.[13] Here, "techniques of production, distribution, and consumption of images, sounds, and texts that had formerly been separate are now all bundled together, mechanical, electronic, and digital techniques are integrated as a matter of course into creative processes, just like the electricity and water supply in our houses.[14] Similar to a city crisscrossed by an underlying infrastructure of electricity lines, sewers, telecommunication cables and district heating pipes, the museum sits on top of a materiality that not only includes concrete floors and air ventilation systems but also 'grey media' such as computer hardware, software technologies and operations.[15] Since changing infrastructure is no easy feat, much of this has grown through our modern era as appendages, sunk into and inside of other structures, social arrangements, and technologies without complete system overhauls.[16]

It is well known, that infrastructure does not grow de novo; it wrestles with the inertia of an installed base and inherits strengths and limitations from that base.[19] Infrastructure is embedded in older systems, structures and technologies. The structure of the contemporary museum as such is a repurposing, a remediation of older forms of itself where the older media: the installed base has not completely disappeared but exists simultaneously and the material shape of

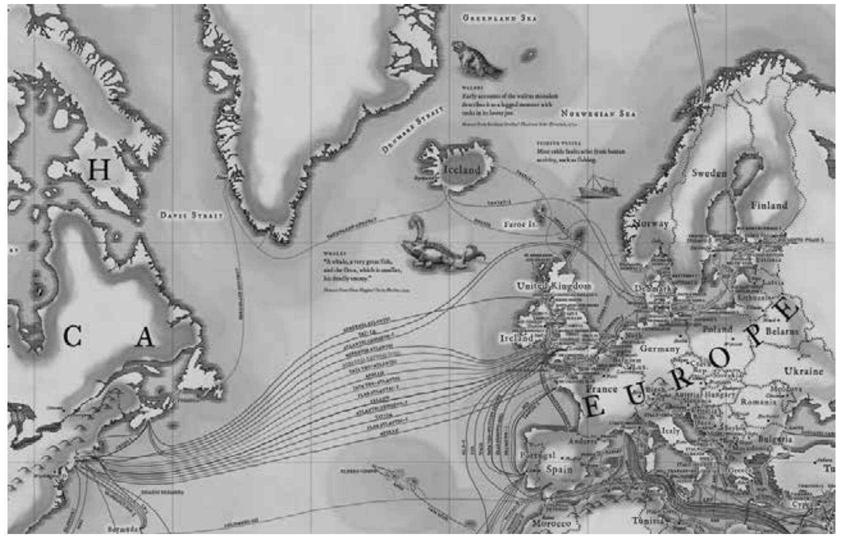


Fig. 1.2. A map of the transatlantic submarine cables that is the backbone of the Internet. The environmental impacts include habitat disturbance, electromagnetic fields that affect sea life, thermal radiation and noise.[17] Map courtesy of Telegeography. All copyrights belong to Telegeography.[18] Image downloaded from http://telegeography.com in March 2016.

the museum itself has emerged from layering of infrastructures over time.[20] Just as optical fibre lines run along old railroad tracks or reuse old telephone cable lines under the Pacific Ocean,[21] mobile telephony bundled with water infrastructure in Lusaka, Zambia, museums have adopted and utilize older systems, material structures in their daily practices and operations.[22]

The current infrastructure of the museum has inherited a long tradition of museum practices (before the technological era) that imposes certain constraints on the flow of content. These are clearly visible by analyzing the various scales of representations, operations and maintenance of the media infrastructures. Here, a multiplicity of technologies, standards, protocols and benchmarks exist side by side interacting with each other affecting the flow of cultural content. Throughout its modern history, the museum has had behind-the-scenes facilities and operations hidden from the public that were synchronized to exhibit collections.

Today, as the level of technological sophistication in media technology, digital assets management and climate control systems has advanced further, it has created invisible technological blackboxes within the museum system resulting in the need for perpetual investment in equipment upgrading and training pockets of specialized personnel who maintain the underlying infrastructure. This has further resulted in a constant energy investment for the museum and brought with it the need to regularly overcome the technological obsolescence of its equipment.[23]

The infrastructure of museum today also extends into the energy-intensive 'Cloud' where our cultural heritage is being increasingly situated and negotiated through. The Cloud is in fact a large concrete-steel warehouse sitting in the middle of nowhere, housing thousands of servers under strict air conditioning, utilizing multiple energy backups and redundancies. The Smithsonian Data Center is the perfect example. It is a nondescript cookie-cutter brick building in the outer suburbs of Herndon Virginia repurposed into a Data Center. The building houses the significant digital collections (the Smithsonian has over 137.7 million objects and specimens) of the Institution's nineteen museums and galleries.[24] Its energy sources are mostly non-renewable. It is the same with all major cloud computing service providers including Amazon and Google. More often than not, these are fed by non-renewable resources.[25] The Internet and the need for online access has transformed this ugly warehouse in Herndon into a home for cultural heritage. With its thousand servers holding millions of digital heritage artifacts, it is the new home to culture that fuels our current understanding and knowledge of history.

Today, the abundance of digitization projects, digital asset management, collections software, use of advanced multitouch media exhibits on the museum floor and the proliferation of cloud collections on the Web imply that museums have undergone a rapid evolutionary change from mere collectors and curators to digital information distribution hubs. The emergence of new media cultural artifacts has also driven the push towards increased digitalization of the museum, towards Collections APIs that have become the virtual interfaces and gateways to banks of cultural heritage. Museum collections interfaced by APIs,

Fig. 1.3. A panoramic view of a remote data centre in Utah that uses up to 1.7 million gallons of water per day available to cool the huge facility (2015). Photograph courtesy of Electronic Frontier Foundation.

backed up by data center capacities are taking over larger amount of tasks that initially were conducted by curators, registrars and museum management towards real physical artifacts. Search capabilities are increasing and engagement with digital works (reproductions) online are expanding manifold vs a traditional museum visit to see 'real objects'. According to Zielinski, cultural heritage is now "information that can be billed to users per bit, it is immaterial whether the information comes in the form of numbers, images, texts or sounds."[26] How would heritage exist in the future when online demand will surpass data center storages, bandwidths and available energy capacities? How will we sustain the process of discovery of knowledge?

Beyond an anonymous energy-intensive data center, the Cooper Hewitt Museum in Manhattan New York itself is repurposed from a 19th century residential mansion. Here, media infrastructures have been embedded into the historic layers of this landmark building to generate increased visitation and economic potential. Beyond digital storage

Fig. 1.4. A multitouch table manufactured by Ideum in the Great Hall of the Cooper Hewitt. Photograph courtesy of Ideum, Inc. / CHSDM. All copyrights belong to Ideum, Inc. and CHSDM. Image downloaded from ideum.com in March 2016.

and distribution systems, the museum is also supported by many other invisible media infrastructures that may not be saving or transmitting content, but that which are essential to the staging and sharing of the content, i.e. exhibition of artifact collections and related audience engagement. These silent infrastructures include the hidden energy-intensive mechanical systems: climate control, electrical distribution, sanitation, building skins and envelopes and security networks. Underneath the skin of the museum run large-scale HVAC ducts that are configured to support preservation-level climatic control not only for artifacts but also for the newly emerging media exhibits. Cabling, lighting systems, fire-safety sensors and electrical points, all are embedded within this infrastructure. Others such as sprinkler systems, water supply and sewage systems form another complex hidden layer inside the walls of the museum. All of these are required for the efficient functioning of the museum's storage, exhibition and media distribution systems. The movement of cultural content depends on these supporting infrastructures and thus could be considered as critical components of media infrastructures of the museum.

Fig. 1.5. Digitization assembly line at CultLab3D. Photograph courtesy of CultLab3D. All copyrights belong to CultLab3D. Image downloaded from cultlab3d.de in March 2016.

This research applies Parks and Starosielski's proposition for adopting an 'infrastructural disposition' to studying the museum, since such an approach foregrounds physical systems and processes of media distribution, brings into relief its unique materialities and compels critical assessment of the relation between technological literacies and public involvement in infrastructure, regulation and use.[27] Attention to the 'grey' media infrastructure — "its technical capacities, temporalities, and spatial distributions also moves us beyond the narrow focus on audiovisual media that has characterized the field of media studies."[28]

Fig. 1.6. A Circular Chart Recorder at the Cooper Hewitt's storage facility. It is microprocessor-based and capable of measuring, displaying, recording, and controlling indoor environment conditions. Photograph by Samir Bhowmik, available under a CC BY 4.0 license.

This approach allows us to examine the energy consumption of the physical systems and the yet invisible material-dependent processes of distribution of content by the museum. The unique materialities of the museum are brought into focus, such as the resources, hardware and software technologies, mechanical systems, personnel and maintenance. We are also able to chart the territories of a greater part of the museum infrastructure that is invisible to the audience, since the museum only reveals itself and its collections through the exhibition spaces (usually a fraction of the entire floor area) and its media exhibits (supporting systems are usually hidden from public view). As it will be seen further on in the study, foregrounding the infrastructure of the museum also has an effect on audience involvement and participation since it opens up the institution for critical examination resulting in expanded engagement by its communities and stakeholders.

THE ENERGY AND EMERGY OF MUSEUM INFRASTRUCTURE 1.2

Traditionally, infrastructures are arranged and embedded across multiple sectors of energy, transportation, water, sanitation and commerce requiring substantial material resources and causing increasing environmental impact. Infrastructural energy use is leading cause of carbon dioxide emissions, the highest being in the energy sector, followed by transportation, industrial, residential and commercial.[29] Recently, it is the ascent of new media technology that has demanded new forms of material infrastructures,[30] to support and shape everyday experience of computing, interactivity and new media.[31] These infrastructures are the data centers that today also support our museum experiences. Their expanding energy footprint is a reason for concern, since museums and cultural institutions are increasingly dependent on digital content storage, computation and transmission.[32] To a large extent, cultural production relies on the exorbitant use of media technology, and at current levels, residential energy use of electronic equipment will rise to 30 percent of the overall global demand for power by 2022, and to 45 percent by 2030, thanks to server farms and data centers.[33]

The very largest data centers, use more power than some large factories. For example, in 2007, the five largest search companies were using about 2 million servers, which consumed about 2.4 gigawatts. By comparison, the US's massive Hoover Dam generated a maximum of about 2 gigawatts.[34] In 2013, U.S. data centers consumed an estimated 91 billion kilowatt-hours of electricity, equivalent to the annual output of 34 large (500-megawatt) coal-fired power plants. Data center electricity consumption is projected to increase to roughly 140 billion kilowatt-hours annually by 2020, the equivalent annual output of 50 power plants, costing businesses $13 billion annually in electricity bills and emitting nearly 100 million metric tons of carbon pollution per year.[35] Meanwhile, Amazon Web Service, the largest cloud services provider chooses to power its infrastructure based solely on lowest electricity prices, without consideration to the impact their growing electricity footprints have on human health or the environment.[36]

Fig. 1.7. *Top*, A server aisle inside a Google Data Center; *bottom*, color coded pipe infrastructure inside a Google Data Centre. Photographs Courtesy by Connie Zhou. All copyrights belong to Connie Zhou and Google. Downloaded from conniezhou.com in May 2016.

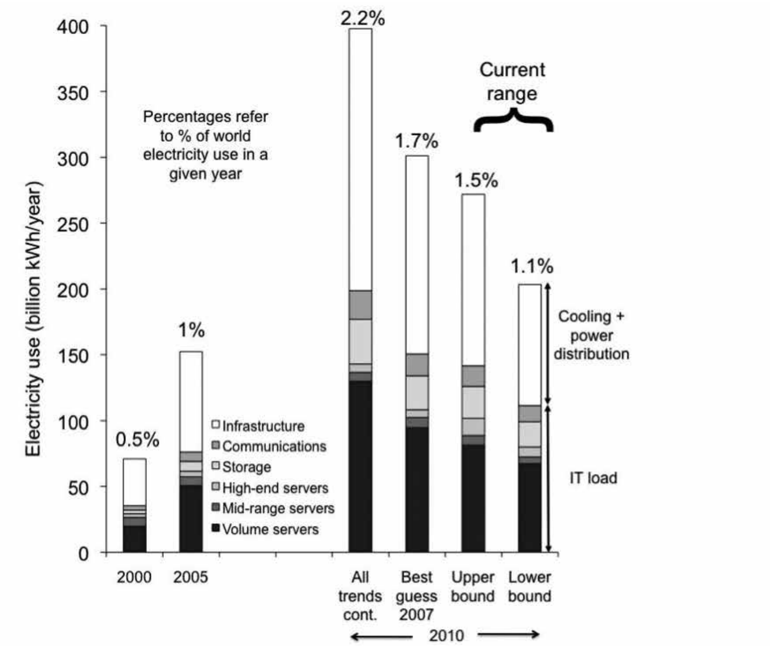


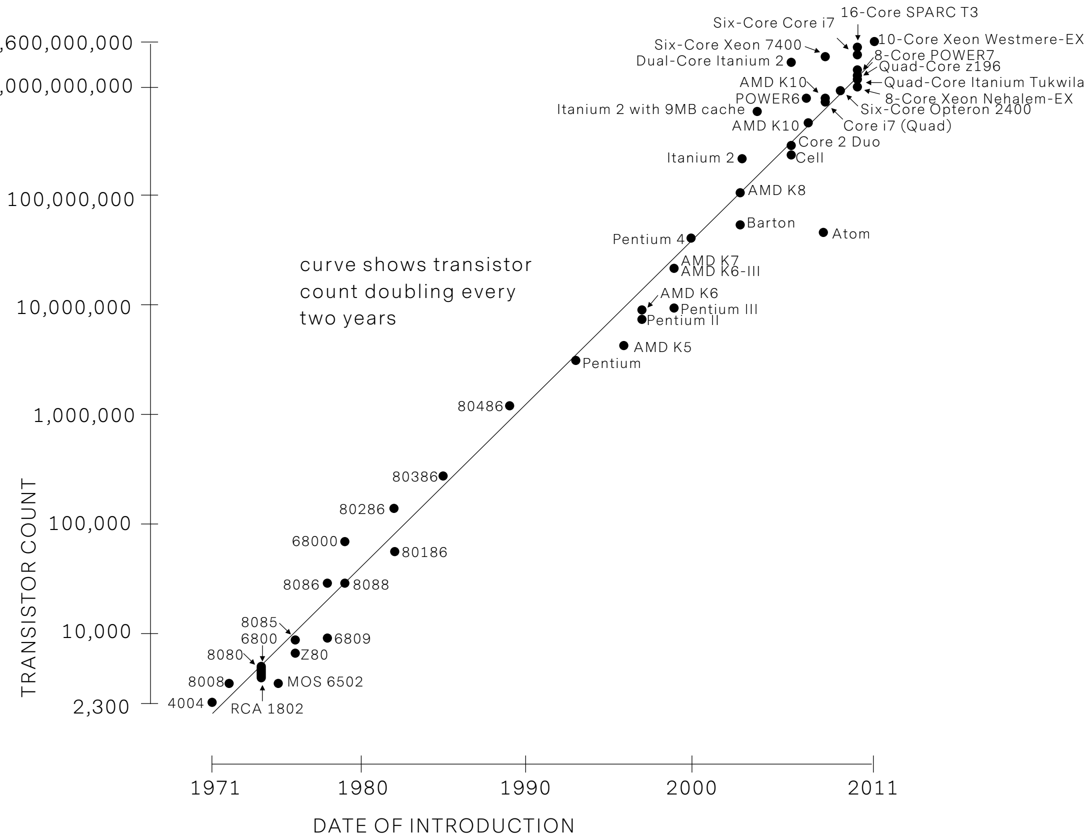
Figure 1.8. Growth In Data Center Electricity Use 2005 To 2010. Illustration by Jonathan G. Koomey, "Growth In Data Center Electricity Use 2005 To 2010," Oakland, CA: Analytics Press, 2011.

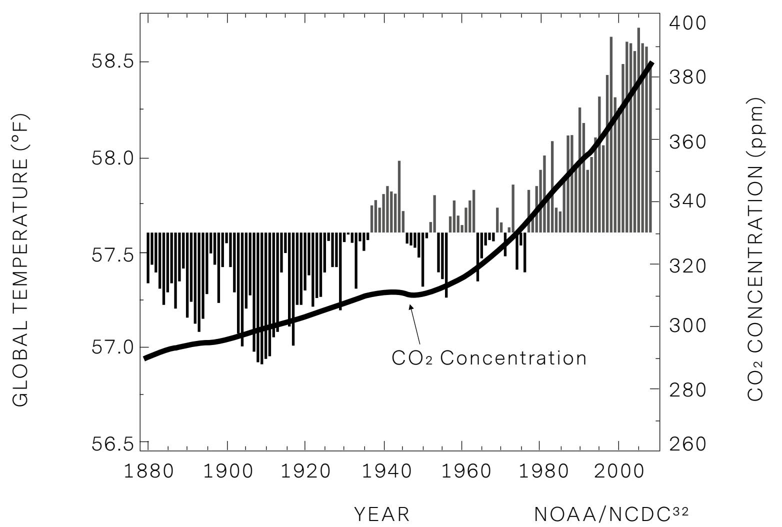
Koomey has documented studies showing that the energy usage of data centers that power our digital societies, has doubled worldwide, up 56% between 2005 and 2010.[37] According to Maxwell and Miller, by 2007 media technologies were responsible for 2.5-3 percent of the world's greenhouse gas emissions.[38] The total worldwide electricity consumption in communication networks grew from 200 TWh per year in 2007 to 330 TWh per year in 2012, corresponding to an annual growth rate of 10.4%[39]. By 2011, Data centers consumed around 1.1% to 1.5% of electricity worldwide and cloud collections were a major user of data center capacities. The consumption went up to 270 TWh in 2012.

Fig. 1.9. An IBM 0665-30 hard disk drive from 1985 showing read arms and circuitry. Photograph by Vanderdecken, distributed under a CC BY-SA 3.0 license.

In an article about infrastructure that supports the Internet in the New York Times, Glanz examined how data centers consume a great deal of energy in order to provide reliability, storing the same information on constantly powered multiple machines to create redundancy.[40] The data center power consumption is dominated by infrastructure electricity use (i.e., cooling and power supply losses). Van Heddeghem et al. note that the actual server power consumption accounts for only about 40%.[41] According to a 2014 Greenpeace Report, energy used by data centers operated by cloud computing companies such as Amazon Web Services ran on 28% Coal, 27% Nuclear, 25% Natural Gas and merely 15% Renewable Energy resources. In fact, petroleum, natural gas and other fossil fuels are running almost all of the major cloud management companies in the world that support our ever-expanding media infrastructure.[42]

Fig. 1.10. *Top,* The doubling of transistor counts every two years or Moore's Law, from 1971 - 2011, illustration by WGSimon, distributed under a CC BY-SA 3.0 license; *bottom,* atmospheric carbon dioxide concentrations and global annual average temperatures over the years 1880 to 2009. Red bars indicate temperatures above and blue bars indicate temperatures below the 1901-2000 average temperature. The black line shows atmospheric carbon dioxide concentration in parts per million. Chart by National Oceanic and Atmospheric Administration.[43]





Power consumption is an important issue in modern computing systems from mobile devices to data servers. It has gathered much attention over the past decade due to the rapidly increasing energy cost of Information and Communication Technologies (ICT) equipment. Data storage devices such as hard drives create a large portion of the energy consumption in these computing systems. The amount of storage required by modern IT services continues to increase and I/O along with disk storage could account for 30% of the energy consumption in a modern server.[44] Even though the ICT industry can be beneficial for environment, such as by reducing the need for traveling, it also causes plenty of emissions when the equipment used by the ICT industry is designed, manufactured, operated, and disposed.[45]

The research group Gartner estimates that the ICT industry produced up to 2% of the worldwide carbon dioxide (CO_2) emissions in 2007.[46] The figure included most of the equipment and infrastructures used by enterprises and governments, but also computers and mobile phones purchased by consumers.[47] A medium-sized data center today has the embodied energy (emergy—the energy required to build the devices and infrastructure that comprise the Internet, see 2.3 for detailed explanation) of the Great Pyramid of Giza and yet a fraction of its permanence.[48]

According to Heddeghem et al., there is no single metric for the ICT footprint.[49] "The increase of ICT equipment has an associated growing impact on our environment. This impact comes in many forms, and is often expressed as a 'footprint'. For example, the manufacturing and usage of ICT equipment have both an associated energy footprint and CO_2 emission footprint. Thus, measuring Energy-consumption of Digital Collections hosted in data centers is currently a challenge. Initial studies conducted show that Data Center energy usage has doubled worldwide. It is up 56% worldwide between 2005 and 2010.[50] Data Centers consume around 1.1% to 1.5% of electricity worldwide and cloud collections are a major user of Data Center capacities.[51] Yet, Granular energy figures for a computing system would entail building an energy calculation model. Several ongoing research studies are being in progress to understand the energy efficiency and carbon footprint of data centers that may host digital collections.[52]

Fig. 1.11. Backup diesel generators inside a Data Center. Photography by Timo Arnall. All copyrights belong to Timo Arnall. Downloaded from http://www.elasticspace.com/2014/05/internet-machine in March 2016.

The findings of this research show that the digital collections of the Cooper Hewitt Smithsonian Design Museum in New York that contain over 273 404 object records and 90 012 image records amounting to a mere 527 Gigabytes are currently stored in a Data Center of the Smithsonian in Virginia (that allows only internal access) has a power consumption of 20 676 kWh annually. According to the U.S. Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator, this is equivalent to 14.4 Metric Tons of Carbon Dioxide Emissions.[53] Correspondingly, the Ateneum Museum in Helsinki hosting art exhibitions has an average annual energy consumption of 2500 - 3000 MWh in the last 5 years.[54] In comparison, Google and other Data Centers hosting the Ateneum's digitized Collections and many other heritage institutions consume over a million megawatts annually.[55] Traditionally, the largest part of the energy consumption for museums come from controlled lighting and the HVAC systems since this is essential to maintain climatic conditions to preserve both the artworks and visitor comfort.[56]

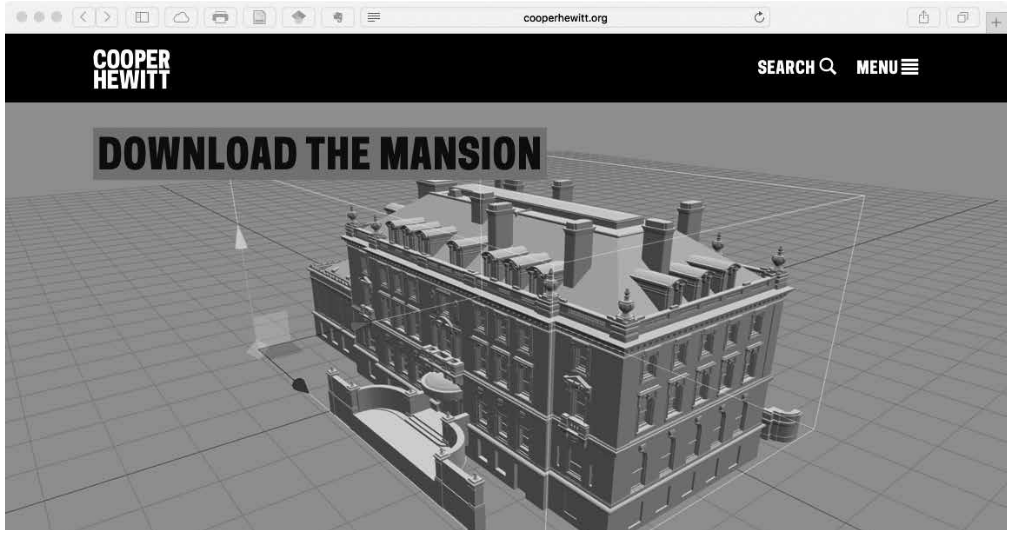


Fig. 1.12. Download the 3D model of the Carnegie Mansion. Screenshot from cooperhewitt.org (2015). All copyrights belong to CHSDM.

Today, museums are increasingly playing a leading role in technological innovation in ICT, especially in the area of digitization, cloud collections, media installations and digitally-embedded museum spaces.[57] For example, the 2013 American Association of Museums Report details innovations that range from robotic digitization, gallery sensors, 3-d printing for pedagogy, networked artifacts to indoor-GPS.[58] These are aimed at enriching the social links between a museum's content and its community, to draw in a larger audience both physical visitation and online audience and to sustain itself as a relevant custodian of cultural-content. These new approaches in digitization and cloud collections have expanded the museum's earlier traditional energy requirements for the basic museological tasks of collections management, display and maintenance. The NMC Horizon Report 2013 Museum Edition anticipates that in the future, a major bulk of museum resources would go into digitization of collections and upgrading media infrastructures.[59]

Fig. 1.13. Virtual reality headsets would become essential for visitor engagement in museums in the future. Here is an example of a virtual reality headset by National Aeronautics and Space Administration (NASA). Photograph courtesy NASA. Public Domain license in the U.S.

In the future, the swift evolution of digital technology in hardware, software and storage systems also implies that a steady monetary and energy investment will be incurred by the museum in improving infrastructures. This, to maintain ongoing accessibility to the museum collections, to maintain the flow of cultural content and to ward off in-built digital obsolescence. All such initiatives necessitate a parallel and relentless infrastructural enhancing for the museum. Soon, it also becomes necessary to quantify the benefits to the museum's audience, taxpayers and the institution itself to justify the large budgets dedicated to energy-intensive media infrastructures.[60]

Therefore, this dissertation calls attention to the media infrastructures of the museum that serve as backdrops to the staging of artifact collections, distributing digital content, providing visitor engagement. The way they are organized, constructed and maintained through the various scales of their operations are significant fields to be studied. The goal here is to move away from the mere analysis of museum content and turn towards understanding how that content moves within the materiality of the museum infrastructure, the energy impact of those movements and how that in turn affects the form of the content and the distributing infrastructure itself. In an era of media globalization how is the museum shaped by the properties and operations of its own media infrastructure?

1.3 RESEARCH CHALLENGE

Our urban and digitally connected societies and institutions worldwide are dependent on energy infrastructures that run on non-renewables, as shown in a 2014 International Energy Agency (IEA) study.[61] Fossil energy use increased most in 2000-2008 and in 2014, the IEA noted that coal accounted for half the increased energy use of the prior decade, growing faster than all renewable energy sources. Thus, oil, coal, and natural gas were the most popular energy fuels.[62] As Diamanti points out, "today there is very little dispute about the planetary costs involved in burning fossil fuels, and even less dispute about the risks involved in extracting ever harder to reach sources of hydrocarbons."[63] Several national and intergovernmental reports validate this point of view.[64]

Today, museums and their collections facilities continue to be powered by energy companies and utilities that depend on non-renewable energies such as oil, gas, coal and nuclear power.[65] They have barely started to monitor and inventory the environmental impact of their building systems and media infrastructure. A lack of information persists about energy use, carbon dioxide emission footprints, and environmental impact of museums.[66] How could a museum, it's media infrastructures, and for that matter, the media industry that is heavily dependent on energy operate responsibly in an age of environmental issues and dilemmas? Especially, how would their media infrastructure, the architectural and the mechanical systems dependent on fossil fuels transform? Will stewardship grow ever stronger as renewable energy increasingly replace fossil fuels?[67] Would museums and cultural institutions have to appropriately scale their media infrastructures and design ecological management policies?

In 2011, I presented a model 'Post-Oil Museum' at the European Science Foundation Conference at Linköping University in Sweden.[68] The Conference was titled: 'Re-Visiting the Contact Zone',[69] based on Clifford's Museum as Contact Zone.[70] The model proposed the need for ecological museums as drivers of regional arts, heritage and economy. The idea originated from several of my own experiences working in the cultural field of architecture, media design and sustainability. I was concerned as an architect and urban designer about the continuing custom of building mega-museums in total indifference to the energy crisis, natural resources used and the high carbon footprints they generated.[71] I was also troubled by the reckless expansion of museums into the technological realm of cloud collections, mass digitization and media exhibits without benchmarks and formal evaluations of their impacts on our environment. How this emerging materiality would eventually become obsolete and end up as electronic waste polluting the environment with their toxic content.[72] At that time, the problem had the appearance of an "Hyperobject, a large body without end, that cannot be usually visualized as a whole,"[73] or as "large and complex as infrastructure that spanned time and space."[74]

Since then, eco-critical media scholars such as Sean Cubitt, Jussi Parikka, Jennifer Gabrys, Richard Maxwell and Toby Miller have all reiterated that media and mediation cannot be separated from their materiality and environmental impacts.[75] Both Parikka and Cubitt say that media has been shaped by energy, materials, obsolescence and beyond that political economies and energy trade. From within Media, Film, Sustainable HCI (Human-computer interaction) and Infrastructure Studies, Parks and Starosielski, Dourish, Holt and Vondereau, Mattern, all have documented and examined the impact of media infrastructures and their effect on ocean ecosystems, energy use, network protocols, data centers, smart cities and institutions.[76] Within Humanities and Museum Studies, the themes of media, collecting, communication, pedagogy, knowledge and memory in museums have been examined by several scholars such as Hooper-Greenhill, Tony Bennett, Paula Findlen, and Susan Pearce.[77] More recently, the virtuality of the museum, digital cultural heritage have been studied by Erkki Huuhtamo, Ross Parry, Fiona Cameron and Sarah Kenderdine;[78] and others such as Michelle Henning, Luke Dearnley, Sebastian Chan and Aaron Cope who have focused on its computing and mediatic aspects.[79]

But, despite much excellent work on these themes of media infrastructures, eco-critical media, museums and digital heritage, media and museum scholars have not yet fully explored when, why and how did the museum became so dependent on media infrastructures, computer hardware and computational processes that are currently sustained by rare earth minerals and fossil fuels. Not many studies have been conducted on the entanglement of media infrastructure, energy and material resources. There is hardly any literature in the field of museum studies in context to energy use, embodied energy and natural resources. How to begin to fulfill this gap? How and where to start a research that would lead to understanding this emerging materiality of museums?

The challenge became evident that to understand the environmental impact of the museum, one had to unearth and excavate the materiality of the museum, or in other words, the vast media infrastructures that are embedded underneath. This catalyzed a need to explore the material nature of the museum, to explore not only the white cube, but that which was behind, under and around the museum, its plethora of black boxes and related energy footprint. Could an enumeration, description and visualization of the internal material infrastructures, energy-intensive operations and processes lead to a better understanding of the environmental footprint of the museum?

The dissertation presented here is a journey through the infrastructural excavation of the museum and implementation of a series of design interventions to explore alternative solutions.[80] The findings show a dynamic but unstable museum, where relentless enhancing of the media and material infrastructure takes place to maintain accessibility to the museum collections, to communicate content to the audience and to ward off in-built obsolescence.[81] This has resulted in the compartmentalization or black-boxing of various components of the museum infrastructure due to the high level of technological systems and competence needed to maintain them.

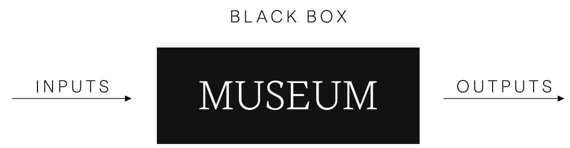


Fig. 1.14. The museum blackbox. Illustration inspired from: Garnet Hertz and Jussi Parikka, “Zombie Media: Circuit Bending Media Archaeology Into An Art Method,” *Leonardo* 45, no. 5 (2012): 426-427.

Just like technological black-boxes below the shiny surfaces of emerging media technologies (that which are not designed to be fixable, with no user serviceable parts inside), much of the museum’s internal complexity remains invisible to its constituents, its mediating role difficult to measure.[82] The energy consumption effected by the invisible infrastructure or ‘expert territory’ is not therefore clearly understood. Today, museums have a fairly large carbon-footprint since they can only be operated and maintained through a series of energy-intensive processes to maintain their collections. As such, the need to balance a museum’s communication effectiveness with the pressures of being ecological is an emerging design challenge.[83]

1.4 THESIS

The challenge to address the materiality of the media infrastructure of the contemporary museum forms one of the key research aims of this dissertation. It seeks to understand ways that the museum's media infrastructure can be ecological without losing its communication effectiveness.

In A Geology of Media, Parikka says that to understand the use of contemporary media we must look at 'deep time' literally that we must investigate material realities that precede media themselves—the earth's history, geological formations, minerals, and energy and that we must aim for a more literal understanding of 'deep time' in geological, mineralogical, chemical, and ecological terms.[84]

> *"Hence geology is not only about the soil, the crust, the layers that give our feet a ground on which to stumble: geology is also a theme connected to the climate change as well as the political economy of industrial and postindustrial production. It connects to the wider geophysical life worlds that support the organic life as much as the technological worlds of transmission, calculation, and storage. Geology becomes a way to investigate materiality of the technological media world. It becomes a conceptual trajectory, a creative intervention to the cultural history of the contemporary."*[85]

According to Parikka, the environment does not just surround our media cultural world, it runs through it, enables it, and hosts it in an era of unprecedented climate change. Not only are rare earth minerals and other metals needed to make our digital media machines work, but that used and obsolete media technologies return to the earth as residue of digital culture, contributing to growing layers of toxic waste for future archaeologists to ponder.[86] Expounding on 'materialities of materials', Parikka argues that:

> *"…we can approach media cultures through the various materials, components, long networks, and genealogies in which media technologies are being produced. Media history is one big story of experimenting with different materials from glass plates to chemicals, from selenium to coltan, from dilute sulphuric acid to shellac silk and gutta percha, to processes such as crystallization, ionization, and so forth."*[87]

Therefore, Parikka asserts that we are forced to consider the history of materiality underlying our seemingly virtual or immaterial practices. This history, according to Allen, will then uncover "our contributions to the geological record over the course of this era primarily showing the effects of technical media: the electrification, then wiring, then wirelessing, of the globe."[88]

Much earlier, in Networks of Power, Thomas Hughes re-examines electrification or the infrastructure for power generation and supply in the twentieth century, to uncover aspects of infrastructural formation, the societies it fostered and the technologies it brought forth. He demonstrates that growth of energy generation is intrinsically tied to the material resources and cultural contexts and as cultural artifacts, they reflect the past as well as the present.[89] According to Hughes, "the analysis of an incoherent, formative period in the history of energy systems was likely to be meaningful to present dilemmas of energy systems and their future growth." Similarly in Mechanization Takes Command, Siegfried Giedion does not present an ideal, unified, progressive or heroic imagery of technology and architecture, but elaborates on the discarded and forgotten bits and pieces of history with an emphasis on the technological fragments of ordinary domestic life.[90]

Thus, in this context, engaging with the 'deep time' of the museum infrastructure can be seen as one entailing both historical and contemporary research through multiple museological practices and processes involving materiality. Or as Zielinski says – "to enter into a relationship of tension with various present-day moments, revitalize them, and render them more decisive."[91] From the history of acquisition of energy-embedded artifacts to documentation of their material properties, from conservation to the architectural needs of exhibitions, from digitization to virtualization of the museum, and most of all the origin of energy-intensive media infrastructure that supports these practices. Embedded within these are computational objects and processes that make up the larger media and technological landscape. According to Dourish, to get a glimpse of the larger picture [or as mentioned earlier, the 'hyperobject' of media infrastructure], we have to begin a foundational engagement with the materiality of media at smaller scales.[92] Perhaps, a thorough material exploration could provide a glimpse into the present-day museological dilemmas associated with the museum's evolving infrastructure and related energy footprints and then onto the bigger picture. Perhaps, this could lead us to what Zielinski emphasizes as un-realized potential uses of technology and assist to create ecological spaces of action.[93]

Thus, the dissertation at first approaches museum infrastructure through Zielinski's 'deep time' media history,[94] and subsequently through Parikka and Ernst's lens of materiality "in terms of its logical structure (informatics) on the one hand and hardware (physics) on the other as opposed to discursive and subjective;[95] and with an attention to the specific materialities behind the processes by which digital experiences are produced.[96] In particular the dissertation focuses on how to enable ecological forms of media-energy planning that could be utilized in the design of media infrastructures?

The thesis responds to this question through the following steps: First, the research needs to excavate and enumerate the invisible infrastructure of the museum, then try to understand what are its energy consuming components. The research then attempts through design interventions to find alternative approaches to media infrastructuring, so that the design of infrastructure itself can make its effects more or less visible.[97] Finally, the research will explore what guidelines should be formulated to enable a critical approach to designing media infrastructures for museums.

METHODOLOGY 1.5

According to Bowker et al., infrastructure studies require drawing together methods that are equal to the ambitions of its phenomenon.[98] In this regard, the analysis of media infrastructure needs multi-modal research – there is no one methodology which is going to prevail, since "infrastructure is 'large' spanning time and space, but it is also 'small' coming in contact with routine and everyday practice".[99] Just like urban infrastructure, media infrastructure is also an assemblage of technological development. It constitutes a layering of old and new media, open and closed black-boxed systems, distribution technologies and hardware superimposed on older and sometimes incompatible infrastructures and practices. The museum is a media monument by itself.

Therefore, the study makes use of multiple methods gathered and customized from the fields of New Media, Media Archaeology, Museum Studies, Infrastructure Studies, Energy Studies, Design Research and Critical making. The study approaches the 'monument' through — "…a methodological preference for rejecting the projection of generalized theories in favor of precise case studies…."[100] According to Ernst, "this method aims to avoid prematurely interpreting archival or archaeological evidence as documents of history but rather isolates this data into discrete series in order to rearrange them and open them for different configurations."[101]

At the precedent level, this dissertation pursued a series of exploratory methods, that starts with an excavation of the Cooper Hewitt Smithsonian Design Museum. Here, 'Excavation' can be understood as a contextualization of the conditions of the media infrastructure in the given case. This followed by a documentation of the existing museum infrastructure. The goal is to explore history as well as to enquire about the transition of the museum to current new media context. The diagrammatics, or diagramming of the museum system assisted in charting the museum system and the flow of content through the museum infrastructure.[102] The practical aspects of the excavation included energy data recording, interviews with museum personnel, metrics, internal reports and site visits.

At the design intervention level, the research was practice-based. It made use of practice-oriented methodologies such as Constructive Design Research, Reflection-in-action, Critical Making, Circuit Bending, and Critical Remediation. It then analyzed the design interventions through an archaeological 'cool' gaze that was enumerative rather than narrative, descriptive rather than discursive, infrastructural rather than sociological, taking numbers into account instead of just letters and images.[103] Several new methodologies were also born within the interventions themselves such as Microstructuring, Self-Publishing, etc., that were defined interactively as the projects progressed.

From the excavation of the museum and the design interventions, insights have been collected and organized into a design framework.

1.6 DESIGN FRAMEWORK

The result of this research was the compilation of primary concepts that could guide the design of ecological media infrastructures. The application of the concepts could happen especially in the museum's planning, renovation, renewal, and retrofitting phase. This is so, since at the initial stage, long-term strategic decisions about design and deployment could be made weighing in life-cycles of technologies, infrastructure and environment.

The primary concepts that emerged from the research are Contextual Interfacing, Media Microstructuring, Critical Making and Critical Remediation. Contextual Interfacing involves interfacing the media infrastructure, old, new & residual in context at the museum, Media Microstructuring is about micro-sizing all tasks, devices and operations, Critical Making addresses the making of media infrastructure to critically address the various components of the museum, experiment new tools and imaginary prototypes and Critical Remediation allows a reflective remediation of media infrastructure and processes of the museum.

The framework needs a comprehensive evaluation in the future and has not been addressed in this study except through their discoveries in the design interventions stage. However it hopes that through this study the energy and environmental impact of media infrastructures of the museum can be opened for discussion.

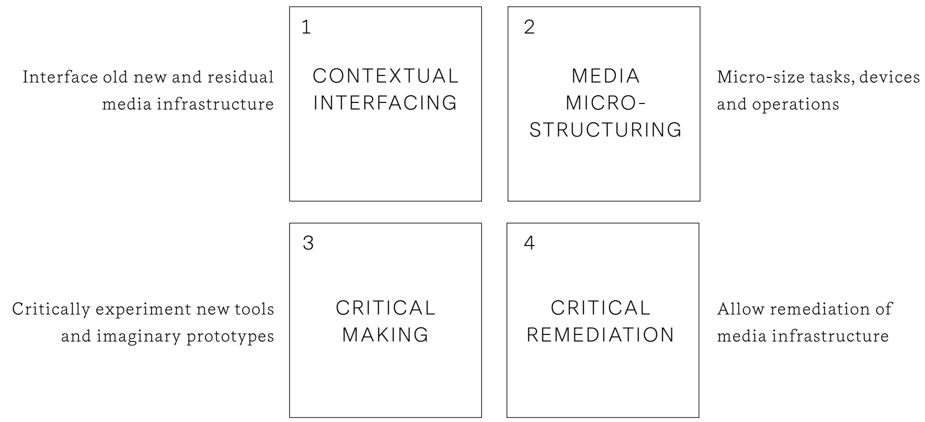


Fig. 1.15. A Design Framework for Media Infrastructures.

DESCRIPTION OF PROJECTS 1.7

In context of this dissertation, the research questions were elaborated through the primary case excavation of the Cooper Hewitt Smithsonian Design Museum, the two design interventions at Hakaniemi, Helsinki and at Gallen-Kallela Museum respectively. Additionally, energy studies were conducted in local heritage institutions in Finland. These are briefly outlined in the following:

CASE EXCAVATION OF COOPER HEWITT SMITHSONIAN DESIGN MUSEUM 2014 - 2015 1.7.1

An on-site research was conducted into the nature of Cooper-Hewitt's digitized collections, energy use of the museum and its base community. The study explored and analyzed ICT (Information & Communication

Technologies)-based processes of the collections of Museum. It examined the links between energy & social metrics of museum's user communities, analyzed carbon footprints and behavior of accessing digital artifacts by community from the museum's Collections Applications programming Interface (API).[104] It explored environmental impact of the materials and processes used to create digital objects. How did the average environmental footprint of a design object change over time, can an energy metadata field be added to object data?The research visit helped gather knowledge about the media infrastructure and the energy consumption of the various components of the museum. This allowed a deep excavation into the contemporary museum system, to understand its benefits and deficiencies. The study provides a contextualization of the problem of museum infrastructure and related energy use.

1.7.2 DESIGN INTERVENTION IN HAKANIEMI MARKET SQUARE, HELSINKI 2012

A public museum installation was implemented that served as a research object in the Hakaniemi Market Square in Helsinki. It explored community participation, domestic energy consumption, and digital media technologies in displaying energy artifacts from a community neighborhood in Helsinki. Here, community residents anonymously exhibited information of their domestic energy artifacts, personal stories and shared their energy use data for the general wellbeing. The intervention demonstrated that a community's contemporary collections, energy-use and personal narratives can be shared and exhibited using a recycled low-energy consuming physical and digital infrastructure. The project showed that a collaborative and participatory installation that mimics a museum could be constructed outside the museum walls. The project has been documented and available on the Web through the following addresses:

RESOURCES
Project Website (static): http://designresearch.aalto.fi/projects/lih/
Digital Archive: Lightishistory.tumblr.com
Programming Codes and 3D Files:
https://github.com/samirbhowmik/Light-is-History

DESIGN INTERVENTION AT GALLEN-KALLELA MUSEUM 2013 - 2014 1.7.3

A collaborative, ecological and low-budget project was implemented for digitizing the collections of the Gallen-Kallela Museum, Espoo with the help of the museum's user community. This was part of digGLAM, a low-cost digitizing infrastructure for small museums developed at the Media Lab Helsinki.[105] Here, community theme days were designed and held at the museum to focus on gathering archival material from its audience. Open source software was used and a low energy consuming robotic scanner was developed to automate the digitization processes.[106] The project allowed the local community of the museum to help digitize and tag their own personal heritage related to the Finnish artist Akseli Gallen-Kallela. The digitized material from these theme days were then fed into a community-participated museum archive placed in the Public Domain. The project has been documented and available on the Web through the following addresses:

RESOURCES
Project Blog: http://sysrep.aalto.fi/digglam/
Digital Archive: http://halooakseli.fi/collections/
Programming Codes and 3D Files: https://github.com/Project-Gado/Project-Gado/tree/master/linux_src/Gado_2

OTHER CASES 1.7.4

Museum Energy-use Surveys were also conducted at two art museums in Finland via survey questionnaires and interviews. These are the Finnish National Gallery in Helsinki and the Gallen-Kallela Museum in

Espoo. The survey aimed to uncover the aspects of energy consump tion related to digital infrastructure, heating air-conditioning & ventilation (HVAC), digital exhibits and digitization.

1.7.5 RESEARCH PERIODS

The overall research spans from the beginning of 2012 until the middle of 2015. The investigation of the Cooper Hewitt Smithsonian Design Museum, through literature had already begun in the middle of 2012 when renovations had started and the museum had closed to the public. A research visit was conducted in 2014 to gather on-site observations. The design and implementation of the intervention at Hakaniemi Market Square took place in 2012. The project at the Gallen-Kallela Museum was conducted between 2013 and 2014. Other case studies and surveys were completed during the same period.

1.8 RESEARCH SCOPE

1.8.1 OBJECTIVE

The objective of the dissertation is to discover ways to develop design methods for incorporating ecological media infrastructures to serve museums.

1.8.2 DISSERTATION FOCUS

The focus of this dissertation is on especially the media infrastructure's planning phase. This was chosen since the planning is where initial long-term strategic decisions about design and deployment could be made considering life-cycles of technologies, infrastructure and environment. This was found to be the least developed area in the design of media infrastructures. Enabling new forms of media-energy planning would impact a museum's technology use and lay the foundation for a museum's digital future.

USERS, PARTICIPANTS & STAKEHOLDERS 1.8.3

Since media infrastructuring is an increasing concern in museum practices today, this dissertation and its outcomes are aimed at the institution and across the various departments contained within such as curatorial, conservation, exhibition, digital, marketing and operations.

First, the main participants of this research's design framework are the members of the museum community, the principal in-house actors and the calibrators of media technology of the museum itself. Secondly, it is aimed at the museum's audience and user communities, those who are the main users of the museum's technology; and finally, the local municipalities and planning authorities who are important stakeholders in the overall planning of community and cultural development.

RESEARCH TARGET 1.8.4

Can a design framework for media infrastructuring be developed through analysis of existing museums and design interventions? The framework would provide key guidelines for museums and their user communities towards shaping a responsible institution. This study intends to focus attention on the relationship between media infrastructures, energy use, emergy and monitoring through the example of the museum. By excavating to understand the museum system, components, operations, emergy and energy use we could trace the nodes and points within the infrastructure that could be subject to design investigations. Then by design interventions, perhaps we could address those complex problems and attempt to find alternatives. The framework would need a thorough evaluation and testing to become a fully functional strategy to guide the design of museum infrastructures in the future.

1.9 STRUCTURE OF THE DISSERTATION

The dissertation in its current form can be best described as being "on the side of the indexical and the archival mode of writing."[107] There is no grand narrative. The study does not attempt to string stories, or build histories. Rather, it works as an archive, as media infrastructure itself without the technological black boxes. Some of the chapters can be read independently in no linear order. And, since the dissertation gets limited by being inscribed in the media technology of writing and print, it attempts to be visual (adding the media layer of photographs, diagrams, and images) along with with extensive citations and notes, so as to allow the reader-researcher to participate and construct their own order of reading and conclusions. [108]

In this first chapter, the research challenge has been introduced accompanied by the concept of the 'Post-Oil Museum'. The chapter goes on to define the main ideas supporting the dissertation and a background of motivations leading to this research. Here, the methodology and aims of the dissertation are also briefly presented. This chapter serves as an outline of the entire dissertation.

The second chapter, Context & Methods, provides an exploration of the context of the research through the perspectives of 'deep time' of museum infrastructures and energy use of the museum system. Here, it charts the problem space between the two leading up to the research scope, research questions and the thesis. Users, participants and stakeholders are also analyzed and the research projects are introduced. The methodologies of research are elaborated in detail and the point of view of this study is clarified.

In the third chapter, Excavation at the Cooper Hewitt Smithsonian Design Museum, the said museum is examined in detail. The case study is at first contextualized and the methodologies of excavation are described. This is followed up by a description of the media infrastructure that includes components, operations, relationships and energy analyses. A part of this archaeology involves diagramming the museum system to chart the visible and invisible infrastructures related to energy consumption and energy embodiment.

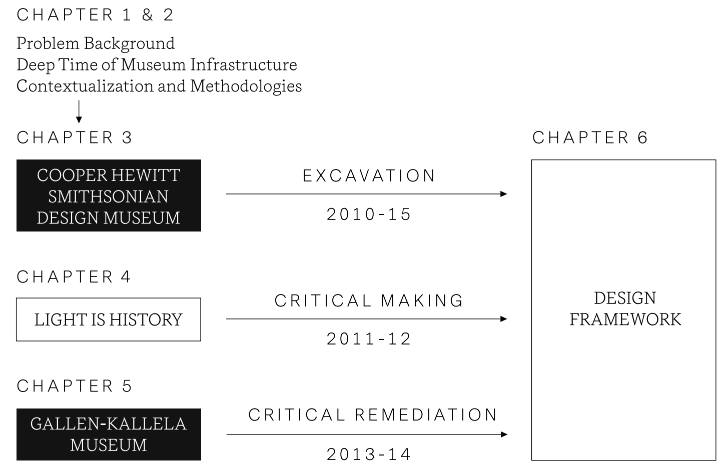


Fig. 1.16. Structure of the study.

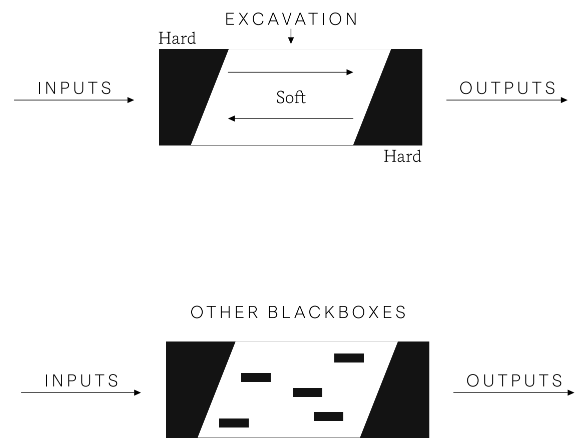


Fig. 1.17. *Top*, Excavation of the museum blackbox; *bottom*, discovery of other blackboxes within the museum blackbox.

The chapters, four and five are the experimental design interventions. The structure followed in both chapters are similar. The analytical approach proceeded from the stage of 'Excavation' as historical and theoretical contextualization of the pre-conditions in the given case, to 'Operative Methodologies' of the 'Intervention'.

Further, the interventions themselves are examined in detail as processual and event-based under Media Infrastructures, that has been grouped under 'Hard' and 'Soft'. The 'Hard' includes material infrastructure such as architecture, mechanical systems, storage, hardware, etc., and the 'Soft' contains the materiality of software such as application programming interfaces, software, operational areas, protocols, algorithms etc. These are followed by a study and analysis of simulations, installation and feedback. The final section quantifies the media infrastructures in terms of energy consumption and embodied energy. Outcomes and lessons learnt are taken forward to the design framework.

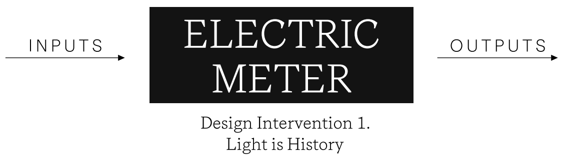


Fig. 1.18. The electric meter blackbox investigated in design intervention 1.

Chapter four, Critical Making of Light is History, follows the entire context, conceptualization, design, making and deployment of a community-participated installation in Helsinki. The project demonstrates how a community's contemporary collections, energy-use and personal narratives could be shared and exhibited using a recycled low-energy consuming media infrastructure.

Chapter five, Critical Remediation at the Gallen-Kallela Museum, examines the making and deployment of the second design intervention, in the form of a semi-autonomous digitization platform where both community artifacts and museum collections were digitized. This intervention illustrates how an inexpensive low-energy consuming

Fig. 1.19. The image scanner blackbox investigated in design intervention 2

digitizing infrastructure for small museums could serve the dual purposes of engaging community and digitize collections.

The concluding chapter, Design Framework for Media Infrastructures synthesizes the findings of the Excavation and Design Interventions from the previous chapters. From these, an overall design framework is generated. The key principles are then composed into four components of the resulting design framework: Contextual Interfacing, Media Microstructuring, Critical Making and Critical Remediation. These components are described, along with specific guidelines followed by examples.

CONTRIBUTIONS 1.10

There is scarce knowledge, studies and data available that is related to this specific research study into energy-consuming media infrastructures of the museum system. As such, novel methods and approaches to examine infrastructure and energy use had to be developed along the way. In addition to a design framework for museum infrastructures, this dissertation presents strategies from within the design interventions that could be utilized for future evaluations.

First, it provides a deep excavation of the media infrastructure of the museum system through the study of the Cooper Hewitt Smithsonian Design Museum, as will be seen in Chapter Three. It initially maps and enumerates the infrastructure to understand the visible and invisible infrastructures that are related to energy consumption and energy embodiment. Through this it shows an alternative method to understand the system and the various black boxes contained within. The dissertation also presents an approach to study the museum's media components, their operative methodologies, relationships and energy analyses. It then opens up approaches to conduct an "epistemological reverse engineering" of the museum via design interventions.[109]

Secondly, the design interventions in Chapters Four and Five present a novel methods in exploring energy use of media infrastructures. Here, they also show that a reflective, remediative and critical 'learning by making' methodologies could be beneficial techniques and strategies to designing media infrastructures. Novel hardware systems along with customized software resulted from these interventions that could be applied to existing museum infrastructures. Key outcomes and lessons from these interventions were taken forward that have informed the emerging framework.

Finally, the dissertation provides a Design Framework in Chapter Six for designing media infrastructures for museums.

1.11 SUMMARY

The challenge to address the materiality of the media infrastructure of the contemporary museum forms one of the key research aims of this dissertation. This complex and historical body of materiality includes not only architecture and mechanical systems but also computers, media devices, software and operations. Museum infrastructure is layered in older systems, structures and technologies, where older forms and processes operate simultaneously. A multiplicity of standards, protocols and benchmarks also exist side by side affecting the daily workings of the museum. Today, as media technologies, digital assets management and climate control systems advance further, it has created invisible technological blackboxes within the museum system, leading to the need for perpetual investment in upgrading infrastructures and training of museum personnel. Additonally, digitization projects, digital asset management, collections software, advanced multitouch media exhibits on the museum floor and the increasing dependence on cloud collections and data centers have resulted in a growing energy investment for the museum and technological obsolescence of its equipment. The dissertation therefore calls attention to the media infrastructures of the museum that serve as backdrops to the staging of artifact collections, distributing digital content and providing visitor engagement. It proposes a design framework extrapolated from a deep archaeological excavation of the museum followed by a series of design interventions. The framework develops and illustrates a novel and critical means of infrastructuring for museums. Although not evaluated by real projects yet, the framework could serve as an exploratory mechanism for museums and designers in the future towards building ecological museums.

NOTES TO CHAPTER ONE

1 Jamie Allen, "Critical Infrastructure," *APRJA Post-Digital Research*, Vol. 3.1 (2014), http://www.aprja.net/?p=1677 (accessed February 10, 2016).

2 Susan Leigh Star and Karen Ruhleder, "Steps Toward An Ecology Of Infrastructure: Design And Access For Large Information Spaces," *Information Systems Research* 7, No. 1 (1996): 111-134, doi:10.1.1.88.3121 (accessed February 10, 2016); Ibid., "Steps Towards An Ecology Of Infrastructure: Complex Problems In Design And Access For Large-Scale Collaborative Systems," 253.

3 Susan Leigh Star, "The Ethnography of Infrastructure," *American Behavioral Scientist* 43, no. 3 (1999): 380, doi: 10.1177/00027649921955326 (accessed February 10, 2016); Allen, "Critical Infrastructure." According to Allen: "as these infrastructural systems ascend from our physical, then from perceptual, then our conscious realities, we are called upon to think about them less and less, and the consequences get more and more gnarly. It gets to the point that even when we would like to find out where the pipes are going, and what is going through them."

4 Brian Larkin, "The Politics and Poetics of Infrastructure," *Annual Review of Anthropology* 42 (2013): 327-343, doi: 10.1146/annurev-anthro-092412-155522 (accessed March 22 2016).

5 Geoffrey C. Bowker, Karen Baker, Florence Millerand, and David Ribes, "Toward Information Infrastructure Studies: Ways of Knowing in a Networked Environment," in *International Handbook of Internet Research*, ed. Jeremy Hunsinger, Lisbeth Klastrup and Matthew M. Allen (Netherlands: Springer, 2010): 97-117, doi: 10.1007/978-1-4020-9789-8_5 (accessed February 10, 2016).

6 Susan Leigh Star and Karen Ruhleder, "Steps Towards An Ecology Of Infrastructure: Complex Problems In Design And Access For Large-Scale Collaborative Systems," (in Proceedings of the Conference on Computer Supported Cooperative Work, Chapel Hill, NC, ACM Press, New York, 1994): 253-264, doi: 10.1145/192844.193021 (accessed February 10, 2016).

7 Cleveland Museum of Art, http://www.clevelandart.org/gallery-one/collection-wall (accessed March 7, 2016).

8 Lisa Parks and Nicole Starosielski, introduction to *Signal Traffic: Critical Studies of Media Infrastructures*, ed. Lisa Parks and Nicole Starosielski (Urbana, Chicago And Springfield: University Of Illinois Press, 2015), 1-27.

9 Lisa Parks, "Stuff You Can Kick": Toward A Theory Of Media Infrastructures," in *Between Humanities And The Digital*, ed. Patrik Svensson and David Theo Goldberg (Cambridge, MA And London: MIT Press,2015a), 355-374.

10 Allen, "Critical Infrastructure." Allen calls this invisible infrastructure as the "grey media of engineering, instrumentation and technical disciplines, a particular color of grey used in the telecommunications industry that, at least in industry folklore, that has been psychologically proven to be the world's most boring color. This cognitive camouflage marks everything technological that is intended to be uniformly dull and uninteresting."

11 Friedrich Kittler, *Gramophone, Film, Typewriter* (Stanford University Press, 1999), xli.

12 Allen, "Critical Infrastructure."

13 Siegfried Zielinski and Silvia M. Wagnermaier, "Depth of Subject and Diversity of Method: An Introduction to Variantology," in *Variantology: On Deep Time Relations of Arts, Sciences and Technologies*, ed. Silvia M. Wagnermeier and Siegfried Zielinski (Köln: Walther König, 2005), 7-12.

14 Ibid., 10.

15 Matthew Fuller and Andrew Goffey, *Evil Media* (MIT Press, 2012), 1-24. Fuller and Goffey also define "grey media" as those, "databases, group-work software, project- planning methods, media forms, and technologies that are operative far from the more visible churn of messages about consumers, empowerment, or the questionable wisdom of the information economy."

16 Star, "The Ethnography of Infrastructure," 381.

17 Ospar Commission, Assessment of the environmental impacts of cables 2009 http://qsr2010.ospar.org/media/assessments/p00437_Cables.pdf (accessed March 6, 2016).

18 Telegeography, Submarine Cable Map 2015 https://www.telegeography.com/telecom-resources/map-gallery/submarine-cable-map-2015/index.html (accessed March 6, 2016).

19 Ibid., 382.

20 Jay David Bolter and Richard Grusin, *Remediation : Understanding New Media* (Cambridge, MA: MIT Press, 2000), 44-50. This is Bolter and Grusin's second remediation by which new digital media exists simultaneously with the existing in a state of multiplicity or hypermediacy, trying to interpret and represent the old in newer ways.

21 Nicole Starosielski, *The Undersea Network* (Durham And London: Duke University Press, 2015), 27-32.

22 Lisa Parks, "Around the Antenna Tree: The Politics of Infrastructural Visibility," (in ACM *SIGGRAPH* 2007 art gallery, ACM, 2007), 345. According to Parks, "wireless infrastructure is defined not only as the capacity, as advertisers would have it, to speak on a phone "anytime anywhere"; it involves the (re)allocation of publicly-owned natural resources, the installation of new equipment on private and public properties, and the restructuring of lifestyles and communities."

23 Christian Remy and Elaine M. Huang, "Addressing the obsolescence of end-user devices: Approaches from the field of sustainable HCI," in *ICT Innovations for Sustainability* (Springer International Publishing, 2015): 257-267, doi: 10.1007/978-3-319-09228-7_15 (accessed February 10, 2016). While the term is often wrongly used as synonym for "planned obsolescence," a concept introduced by marketers in the beginning of the 20th century, the traditional meaning of the word does not imply any planned action or bad intent. For the domain of consumer electronics, obsolescence can simply be used to describe the logical conclusion of the rapid development of technology.

24 Smithsonian Web. 2015. Smithsonian Institution (2010). Creating a Digital Smithsonian. Digitization Strategic Plan FY 2010 to FY 2016. Retrieved May 25, 2015, from http://www.si.edu/Content/Pdf/About/2010_SI_Digitization_Plan.pdf

25 James Glanz, "Online Cloud Services Rely On Coal Or Nuclear Power." *New York Times*, April 17, 2012, http://www.nytimes.com/2012/04/18/business/energy-environment/cloud-services-rely-on-coal-or-nuclear-power-greenpeace-says.html?_r=0 (accessed September 17, 2014).

26 Siegfried Zielinski, *Deep Time Of The Media: Toward An Archaeology Of Hearing And Seeing By Technical Means* (Cambridge, MA: MIT Press, 2006), 273.

27 Parks and Starosielski, *Signal Traffic: Critical Studies of Media Infrastructures*, 5-6.

28 Jeremy Packer and Stephen B. Crofts Wiley, "Strategies for Materializing Communication," *Communication and Critical/Cultural Studies* 9, no. 1 (2012): 107-113, doi: 10.1080/14791420.2011.652487 (accessed February 10, 2016).

29 Steven J. Davis, Ken Caldeira, and H. Damon Matthews, "Future CO2 emissions and climate change from existing energy infrastructure," *Science* 329, no. 5997 (2010): 1330-1333, doi: 10.1126/science.1188566 (accessed February 11, 2016).

30 Packer and Crofts Wiley, "Strategies for Materializing Communication," 107.

31 Matthew G. Kirschenbaum, *Mechanisms: New Media and the Forensic Imagination* (MIT Press, 2012).

32 Larry Johnson, Samantha Adams Becker, Alexander Freeman, "NMC Horizon Report: 2015 Museum Edition" (Austin, Texas: The New Media Consortium, 2015), http://www.nmc.org/publication/nmc-horizon-report-2015-museum-edition/ (accessed February 11, 2016). According to the NMC Horizon Report (2015), technology is now a focal point of budgetary considerations, and museum leaders are considering long-term plans that expand technological infrastructure and digital tools to meet visitors where they are, particularly through their smartphones; Elizabeth E. Merritt and Philip M. Katz, "TrendsWatch 2013: Back to the Future," (Center for the Future of Museums, American Alliance of Museums, 2013), 24-29, http://aam-us.org/docs/center-for-the-future-of-museums/trendswatch2013.pdf (accessed February 11, 2016).

33 Richard Maxwell and Toby Miller, *Greening the Media* (Oxford And New

York: Oxford University Press, 2012), 22-41; Toby Miller, "The Art of Waste: Contemporary Culture and Unsustainable Energy Use," in Signal Traffic: Critical Studies Of Media Infrastructures, ed. Lisa Parks and Nicole Starosielski (Urbana, Chicago And Springfield: University Of Illinois Press, 2015), 137-156.

34 George Lawton, "Powering Down the Computing Infrastructure," *Computer 2* (2007): 16-19, http://www.computer.org/csdl/mags/co/2007/02/r2016.pdf (accessed February 11, 2016).

35 Josh Whitney and Pierre Delforge, "Data Center Efficiency Assessment," Natural Resources Defense Council, August 2014, http://www.nrdc.org/energy/files/data-center-efficiency-assessment-IP.pdf (accessed February 11, 2016).

36 Glanz, "Online Cloud Services Rely on Coal or Nuclear Power," *New York Times*, April 17, 2012; Gary Cook, Tom Dowdall, David Pomerantz, and Yifei Wang, "Clicking clean: how companies are creating the green internet April 2014," Greenpeace, Washington DC, http://www.greenpeace.org/usa/wp-content/uploads/legacy/Global/usa/planet3/PDFs/clickingclean.pdf (accessed February 9, 2016).

37 Jonathan G. Koomey, "Growth In Data Center Electricity Use 2005 To 2010," Oakland, CA: Analytics Press, Completed At The Request Of The New York Times (2011), http://www.missioncriticalmagazine.com/ext/resources/MC/Home/Files/PDFs/Koomey_Data_Center.pdf (accessed February 9, 2016). Koomey's calculations of total electricity use is the sum of servers, storage, communications, and infrastructure; Jonathan G. Koomey, "Estimating Total Power Consumption By Servers In The Us And The World," Final Report (2007), http://energy.lbl.gov/EA/mills/HT/documents/data_centers/svrpwrusecompletefinal.pdf (accessed February 9, 2016). Koomey shows that total power used by servers represented about 0.6% of total U.S. electricity consumption in 2005. "When cooling and auxiliary infrastructure are included, that number grows to 1.2%, an amount comparable to that for color televisions. The total power demand in 2005 (including associated infrastructure) is equivalent (in capacity terms) to about five 1000 MW power plants for the U.S. and 14 such plants for the world. The total electricity bill for operating those servers and associated infrastructure in 2005 was about $2.7 B and $7.2 B for the U.S. and the world, respectively."

38 Maxwell and Miller, *Greening the Media*, 22-41. Maxwell and Toby Miller highlight how media technologies and ecosystems are intricately tied to each other, that media technologies have contributed to and deepened the climate change crisis.

39 Ward Van Heddeghem, Sofie Lambert, Bart Lannoo, Didier Colle, Mario Pickavet, and Piet Demeester, "Trends in worldwide ICT electricity consumption from 2007 to 2012," *Computer Communications* 50 (2014): 64, doi: 10.1016/j.comcom.2014.02.008 (accessed February 9, 2016).

40 Glanz, "Online Cloud Services Rely on Coal or Nuclear Power," *New York Times*, April 17, 2012. According to Glanz, data centers use around 30 gigawatts of electricity and can waste most of that energy, up to 90 percent of it in maintaining redundancies.

41 Van Heddeghem et al., "Trends in worldwide ICT electricity consumption from 2007 to 2012," 64.

42 Cook et al., "Clicking clean: how companies are creating the green internet April 2014," Greenpeace, Washington DC, http://www.greenpeace.org/usa/wp-content/uploads/legacy/Global/usa/planet3/PDFs/clickingclean.pdf (accessed February 9, 2016).

43 National Oceanic and Atmospheric Administration, Global Climate Change Indicators, https://www.ncdc.noaa.gov/indicators/ (accessed March 7, 2016).

44 Karthick Rajamani, Charles Lefurgy, Soraya Ghiasi, Juan C. Rubio, Heather Hanson, and Tom Keller, "Power Management For Computer Systems And Datacenters," (in Proceedings of the 13th International Symposium on Low-Power Electronics and Design, 2008), 11-13, https://www.researchgate.net/profile/Charles_Lefurgy/publication/220847176_Power_management_solutions_for_computer_systems_and_datacenters/links/0fcfd50d271e7e5c09000000.pdf (accessed February 11, 2016).

45 Pollution associated with mining for rare earth metals, and waste through improper disposal of broken or end-of-life equipment can also be considered as part of the environmental footprint.

46 Christy Pettey, "Gartner Estimates ICT Industry Accounts For 2 Percent Of

Global CO2 Emissions," Gartner, April 26, 2007, https://www.gartner.com/newsroom/id/503867 (accessed February 11, 2016).

47 Tommi Mäkelä and Sakari Luukkainen, "Incentives To Apply Green Cloud Computing," *Journal Of Theoretical And Applied Electronic Commerce Research* 8, no. 3 (2013): 74-86, http://dx.doi.org/10.4067/S0718-18762013000300006 (accessed February 11, 2016).

48 Vaclav Smil, *Energy In Nature And Society: General Energetics Of Complex Systems* (Cambridge, MA: The MIT Press, 2008), 173-202.

49 Van Heddeghem et al., "Trends in worldwide ICT electricity consumption from 2007 to 2012," 64.

50 Koomey, "Growth In Data Center Electricity Use 2005 To 2010," 3.

51 Ibid.

52 Michael Pawlish, Aparna S. Varde, and Stefan A. Robila, "Cloud Computing for Environment-Friendly Data Centers," (in Proceedings of the Fourth international workshop on Cloud data management, ACM, 2012):43-48, doi: 10.1145/2390021.2390030 (accessed February 11, 2016); Toni Mastelic, Ariel Oleksiak, Holger Claussen, Ivona Brandic, Jean-Marc Pierson, and Athanasios V. Vasilakos. "Cloud computing: survey on energy efficiency," ACM Computing Surveys (CSUR) 47, no. 2 (2015): 33, doi: 10.1145/2656204 (accessed February 11, 2016). Studies show that standard energy efficiency techniques do not work for cloud computing environments. "This is due to the stratification of the cloud computing infrastructure, which comprises systems and components from different research areas, such as power supply, cooling, computing, and more. Optimizing these systems separately does improve the energy efficiency of the entire system; however, applying shared energy-efficiency techniques to multiple systems or their components can significantly improve energy efficiency if the techniques are aware of their interactions and dependencies."

53 United States Environmental Protection Agency, http://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (accessed February 11, 2016).

54 Interview with Kari Peiponen, IT Manager, Finnish National Gallery, personal communication, 2014.

55 Whitney and Delforge, "Data Center Efficiency Assessment." 5-6.

56 Sandra Mendler and William Odell, *The HOK Guidebook To Sustainable Design* (John Wiley & Sons, 2000), 208.

57 Larry Johnson, Samantha Adams Becker, Alexander Freeman, "NMC Horizon Report: 2013 Museum Edition," (Austin, Texas: The New Media Consortium, 2013), http://redarchive.nmc.org/publications/2013-horizon-report-museum (accessed February 11, 2016).

58 Merritt and Katz, "TrendsWatch 2013: Back to the Future."

59 Johnson, Becker and Freeman, "NMC Horizon Report: 2013 Museum Edition."

60 Johnson, Becker and Freeman, "NMC Horizon Report: 2015 Museum Edition." According to the NMC Horizon Report (2015): "crucial to understanding the complexity of this challenge is acknowledging that the ever-changing technological landscape favors long-term strategies, which incorporate flexible approaches to technology integration and a broader perspective about what types of skilled professionals are needed in museums. Yet institutions are often faced with budgetary limitations that hinder their ability to hire and train staff that can lead or contribute to digital initiatives including programmers, designers, and gallery technicians."

61 International Energy Agency, *World Energy Outlook 2014*, http://www.worldenergyoutlook.org/weo2014/ (accessed February 9, 2016). According to this report, the world energy consumption by power source was oil 31.4%, coal 29.0%, natural gas 21.3%, biofuels and waste 10.0%, nuclear 5.8%, and 'other' (hydro, peat, solar, wind, geothermal power, etc.) 1.1%.

62 Ibid.

63 Jeff Diamanti, foreword to *Energy and Experience: An Essay In Nafthology* by Antti Salminen and Tere Vaden (Chicago: MCM, 2013), http://www.mcmprime.com/files/Energy-and-Experience.pdf (accessed February 9, 2016).

64 United States Environment Protection Agency (Last updated 12 December, 2015): http://www3.epa.gov/climatechange/ghgemissions/global.html (accessed February 9, 2016); Intergovernmental Panel on Climate Change 5th

Assessment Report (2014), https://www.ipcc.ch/report/ar5/wg3/ (accessed February 9, 2016); European Union Emission Database for Global Atmospheric Research (2015), http://edgar.jrc.ec.europa.eu (accessed February 9, 2016).

65 Victoria and Albert Museum, "Sustainability at the V&A," http://www.vam.ac.uk/content/articles/s/v-and-a-sustainability/ (accessed February 9, 2016). As of January 23, 2016, The Victoria and Albert Museum mentions in its website as being one of the first museums to have calculated its carbon footprint. The exercise involved calculating for 2007/08 the carbon impact of utilities, IT, the V&A Museum of Childhood in Bethnal Green, headline and touring exhibitions, stores and business travel.

66 Stephen Ruth, "Reducing ICT-Related Carbon Emissions: An Exemplar For Global Energy Policy?." *IETE Technical Review* 28, No. 3 (2011): 207-211, doi: 10.4103/0256-4602.81229 (accessed February 9, 2016). Carbon Dioxide (CO2) is considered as a greenhouse gas that absorbs and emits radiation to the earth's surface. CO2 is a primary cause of the Greenhouse effect, a process by which radiation from the planet's atmosphere warms it's surface to a temperature above what it would be in the absence of its atmosphere.

67 Barry Lord, "The 'Energy Debate' Is Really A Revolution In What We Think About Everything." *Newsweek*, July 2015 Online Edition, http://europe.newsweek.com/energy-debate-really-revolution-what-we-think-about-everything-329965 (accessed February 9, 2016).

68 Richard Heinberg, "Back to the Post-Oil Future," *Red Pepper*, February 2005, http://www.redpepper.org.uk/Back-to-the-post-oil-future/ (accessed February 9, 2016).The term 'Post-Oil' can be traced back to journalist Richard Heinberg, the author of several books on energy and sustainability crises. According to him, the Post-Oil age stands for the uncharted territory for human societies that lies in a future period of energy decline beyond the peak of global oil production. This age would be one of challenges to adjust to the new realities of perpetual economic downturns, shortages of global food production and regional conflicts over scarce resources. Heinberg suggests a fundamental change of direction for industrial societies in a Post-Oil era: from the larger, faster and more centralized, to the smaller, slower and more local; from competition to cooperation; and from boundless growth to self-limitation. Accordingly, Heinberg's Post-Oil future envisions "a true 'energy' security that would arrive only with community solidarity and interdependence".

69 James Clifford, Routes: Travel And Translation In The Late Twentieth Century (Cambridge, MA: Harvard University Press, 1997), 188-219. Clifford says that the museum can become a space and a framework of action that benefits both itself and the cultures whose artifacts it shows.

70 Samir Bhowmik and Lily Diaz, "Hot Stones and Cool Digitals: Sustainable Contact Zones for Intangible Cultural Heritage in Finland," *International Journal of Intangible Cultural Heritage,* vol.11. 2016, 162-171.

71 'Post-Oil' can also be attributed to a curated exhibition: 'The Post-Oil City - The History of the Future of the City' in Stuttgart, 2009, followed by another in Berlin, 2010 that gathered plausible solutions for urban society non-dependent on fossil energies. Its basic premise: Climate change, the finite nature of fossil fuels, and the world's financial and systemic crises allow new forms of urban planning to provide a laboratory for social as well as ecological change. See: Nikolaus Von Kuhnert and Anh-Linh Ngo, "Post-Oil City,", *Arch+*, 196/197 (2010): 10-11, http://www.archplus.net/home/archiv/artikel/46,3205,1,0.html (accessed February 9, 2016). The exhibition was curated by Von Kuhnert and Ngo and organized by Ifa-galerie and Arch+ Zeitschrift für Architektur und Städtebau in Berlin; Larry Busbea, *Topologies: The Urban Utopia In France, 1960-1970* (Cambridge, MA: The MIT Press, 2007), 4-7. Busbea investigates the cybernetic and theoretical models that intrigued the French designers who privileged the forms of megastructures, attempting to re-connect architecture to the greater social meaning behind infrastructural systems.

72 Jennifer Gabrys, *"Digital Rubbish." A Natural History of Electronics* (University of Michigan Press, 2011).

73 Timothy Morton, *Hyperobjects : Philosophy and Ecology After the End of the World* (Minneapolis: Univ Of Minnesota Press, 2013),1-24. According to Morton, Hyperobjects refer to things that are massively distributed in time and space relative to humans (and not merely collections, systems and assemblages of other objects), such as Global Warming that cannot be directly seen, but can be thought and computed.

74 Bowker et al., "Toward Information Infrastructure Studies: Ways of Knowing in a Networked Environment," 97.

75 Sean Cubitt, *Finite Media: Environmental Implications of Digital Technology*.

(Duke University Press, 2016b, forthcoming); Jussi Parikka, *A Geology of Media* (Minneapolis: University Of Minnesota Press, 2015); Jennifer Gabrys, *"Digital Rubbish." A Natural History of Electronics* (University of Michigan Press, 2011); Richard Maxwell and Toby Miller, *Greening the Media* (Oxford And New York: Oxford University Press, 2012).

76 Lisa Parks and Nicole Starosielski, *Signal Traffic: Critical Studies of Media Infrastructures* (Urbana, Chicago And Springfield: University Of Illinois Press, 2015).

77 Eileen Hooper-Greenhill, ed, *Museum, Media, Message* (London and New York: Routledge, 1995); Tony Bennett, *The Birth Of The Museum: History, Theory, Politics, Culture (*London: Routledge, 1995); Paula Findlen, *Possessing Nature: Museums, Collecting, And Scientific Culture In Early Modern Italy* (University Of California Press, 1994); Susan Pearce, *On Collecting: An Investigation into Collecting in the European tradition (*London and New York: Routledge, 2013).

78 Erkki Huuhtamo, "On the Origins of the Virtual Museum," in *Museums in a Digital Age*, edited by Ross Parry (London and New York: Routledge, 2010), 121-135; Fiona Cameron and Sarah Kenderdine, *Theorizing Digital Cultural Heritage: A Critical Discourse.* (Cambridge, MA: MIT Press, 2007); Ross Parry, ed, *Museums in a Digital Age (*London and New York: Routledge, 2010).

79. Luke Dearnley, "Reprogramming The Museum," in Museums and the Web 2011: Proceedings. Toronto: Archives & Museum Informatics, published March 31, 2011. http://www.museumsandtheweb.com/mw2011/papers/reprogramming_the_museum (accessed November 9, 2015); Sebastian Chan and Aaron Cope, "Strategies against Architecture: Interactive Media and Transformative Technology at the Cooper Hewitt, Smithsonian Design Museum," *Curator: The Museum Journal*, 58: 352–368, doi: 10.1111/cura.12118 (accessed February 16, 2016); Michelle Henning, *Museums, Media and Cultural Theory* (UK: Open University Press, 2006).

80 Here, excavation refers to a historical contextualization followed by a documentation of the existing museum infrastructure. The goal is to explore history as well as to enquire about the transition of the museum to current new media context.

81 Remy and Huang, "Addressing the obsolescence of end-user devices: Approaches from the field of sustainable HCI," 257-267. According to Remy and Huang, the term obsolescence is used here to describe the conditions of technical objects and media equipment to become outdated and lose their usefulness.

82 Bruno Latour, "On Technical Mediation." *Common Knowledge* 3, no. 2 (1994): 29-64.

83 Massimo Negri, "10 Reflections About Sustainability In Museums (And The Global Financial Crisis)," (in Proceedings of the Kenneth Hudson Seminar 2010 'European Museums And The Global Economic Crisis: Impact, Problems, Reactions', Volterra, Italy, November 19, 2010), 11-16, http://www.europeanmuseumacademy.eu/4/upload/kh_seminar_proceedings.pdf (accessed February 10, 2016).

84 Jussi Parikka, *A Geology of Media*, 35.

85 Ibid., 1-18.

86 J.R. Carpenter, review of *A Geology of Media*, by Jussi Parikka, Furtherfield (June 9, 2015), http://www.furtherfield.org/features/reviews/massive-media-geology-media-book-review (accessed February 10, 2016). According to Carpenter, within this geologically inflected materialism, a history of media is also a history of the social and environmental impact of the mining, selling, and consuming of coal, oil, copper, and aluminum. Accordingly, the history of media is also a history of research, design, fabrication, and the discovery of chemical processes and properties such as the use of gutta-percha latex for use the insulation of transatlantic submarine cables, and the extraction of silicon for use in semiconductor devices.

87 Jussi Parikka, "New materialism as media theory: Medianatures and dirty matter," Communication and Critical/Cultural Studies 9, no. 1 (2012): 95-100, doi: 10.1080/14791420.2011.626252 (accessed March 22, 2016).

88 Jamie Allen, "Critical Infrastructure," *APRJA Post-Digital Research*, Vol. 3.1 (2014), http://www.aprja.net/?p=1677 (accessed February 10, 2016).

89 Hughes, *Networks of Power: Electrification in Western Society, 1880-1930*, 461-465.

90 Siegfried Giedion, *Mechanization Takes Command: A Contribution to Anonymous History* (New York: Oxford University Press, 1948); Mirjana Lozanovska, "Thought and Feeling in Giedion's Mechanization Takes Command" in Proceedings of the Society of Architectural Historians, Australia and New Zealand: 30, Open, edited by Alexandra Brown and Andrew Leach (Gold Coast, Qld: SAHANZ, 2013), vol. 2, 879-889, http://wphna.org/wp-content/uploads/2014/06/2013-07-Mirjana-Lozanovska-Mechanization-TC.pdf (accessed February 10, 2016).

91 Zielinski, *Deep Time Of The Media: Toward An Archaeology Of Hearing And Seeing By Technical Means*, 11.

92 Paul Dourish, "Protocols, Packets And Proximity," in *Signal Traffic: Critical Studies Of Media Infrastructures,* ed. Lisa Parks and Nicole Starosielski (Urbana, Chicago And Springfield: University Of Illinois Press, 2015), 183-204.

93 Zielinski, *Deep Time Of The Media: Toward An Archaeology Of Hearing And Seeing By Technical Means*, 1-11.

94 Ibid., 1-11.

95 Wolfgang Ernst, "Does The Archive Become Metaphorical In Multi-Media Space?" in *New Media, Old Media: A History And Theory Reader*, ed. Thomas Keenan and Wendy Hui Kyong Chun (New York: Routledge, 2006), 105-123, https://is.muni.cz/el/1421/jaro2012/FAVBPa05/um/wolfgang_ernst_dis_continuities_does_archive_become_metaphorical_in_multi-media_space.pdf (accessed February 10, 2016); Jussi Parikka, *A Geology of Media* (Minneapolis: University Of Minnesota Press, 2015), 35.

96 Dourish, "Protocols, Packets And Proximity," 183-204.

97 Geoffrey C. Bowker, Stefan Timmermans and Susan Leigh Star, "Infrastructure And Organizational Transformation: Classifying Nurses' Work," (London: Chapman And Hall, 1996), 344-370, doi 10.1007/978-0-387-34872-8_21 (accessed February 10, 2016).

98 Bowker et al., "Toward Information Infrastructure Studies: Ways of Knowing in a Networked Environment," 113.

99 Ibid.

100 Wolfgang Ernst, *Digital Memory and the Archive* (University of Minnesota Press, 2013), 44.

101 Ibid.

102 Jussi Parikka, "Operative Media Archaeology: Wolfgang Ernst's Materialist Media Diagrammatics," *Theory, Culture & Society* 28, no. 5 (2011): 52-74. The diagram shows how a machine or system operates, a way to understanding visually the flow of signals in a structural way.

103 Wolfgang Ernst, "Media Archaeography: Method And Machine Versus History And Narrative Of Media," 239-255.

104 An API (application program interface) is a set of routines, protocols, and tools for building software applications. The API specifies how software components should interact and APIs are used when programming graphical user interface (GUI) components. A good API makes it easier to develop a program by providing all the building blocks.

105 DigGLAM 2013-2014, http://sysrep.aalto.fi/digglam/2013/08/30/hello-world/ (accessed March 22, 2016).

106 Open Source here refers to software with its source code made available by the copyrights holder for anyone to study, make changes and further redistribute to anyone, for any purpose. See Andrew M. St. Laurent, *Understanding Open Source and Free Software Licensing*, O'Reilly Media. 2008, 4.

107 Ernst, *Digital Memory and the Archive*, 45.

108 Ibid, 45-48. Here, Ernst quotes Stephen Bann —"The self-contained nature of visual evidence (as opposed to an extract from a text) enables the reader to establish an order for the visual in its own medium." See Stephen Bann, *Romanticism and the Rise of History* (New York: Twayne, 1995), 88.

109 Garnet Hertz and Jussi Parikka, "Zombie Media: Circuit Bending Media Archaeology Into An Art Method," *Leonardo* 45, no. 5 (2012): 426, doi:10.1162/LEON_a_00438 (accessed February 12, 2016).

CONTEXT AND METHODS

2.1 INTRODUCTION

This chapter aims to contextualize the research for the thesis. The contextualization happens over three sections, based on literature studies, by which both the history and contemporary state of the field is presented and analyzed. This history works both backwards and forwards, a non-linear history that provides the context for guiding this research and set up the foundation for the excavation and design interventions. The contextualization is followed by an overview of methods utilized in this dissertation.

In 2.2., we begin with a brief 'deep time' contextualization of museums with regard to media infrastructure. The goal was to uncover the media history as well as to enquire about the transition of the museum to current new media context. We explore the past in the Pre-mediatic museum and trace the rise of the Mediatic museum through literature and examples. The study does not encompass the entire history of development of the museum, rather explores episodes, missed opportunities and turning points, that in Zielinski's terms are 'attractive foci', – "where possible directions for development were tried out and paradigm shifts took place."[1] In 2.3, we examine the concepts of energy and embodied energy through the entanglements with the museum's media infrastructure. We relate the concept of 'energy' itself to the museum and why its measurement is vital to the study. What does embodied energy have to do with the museum and media infrastructure? We explore black boxes and the effect of black boxing on the museum. Finally, we briefly examine sustainability, both at the broader environmental level and at the scope of media and design. In 2.4, we examine details and scope of the problem space (entanglements) between media infrastructures of the museum and energy. We then define the scope and thesis of this research project.

Section 2.5, describes the methodology of this dissertation. The multi-disciplinary and practice-based nature of the dissertation necessitated a wide assortment of methods. These methods for example range from Excavation, Contextualization, Critical Making to Critical Remediation. They are organized under two main sections, the first being the methods applied to study the museum infrastructure, and secondly, the methods utilized in the design interventions. We also discuss the reasons for adopting the varied methods to this study. This chapter concludes with a clarification of roles and a brief description of point of view of the research.

DEEP TIME OF MUSEUM INFRASTRUCTURE 2.2

In Deep Time of the Media, media archaeologist Siegfried Zielinski introduces us to a history of the hidden layers of media development that are ignored in current day media practices.[2] Here, a varied exchange between artistic practices, science and technology is charted through history and works that are documented as 'deep time' media experiments in contrast to contemporary media culture.

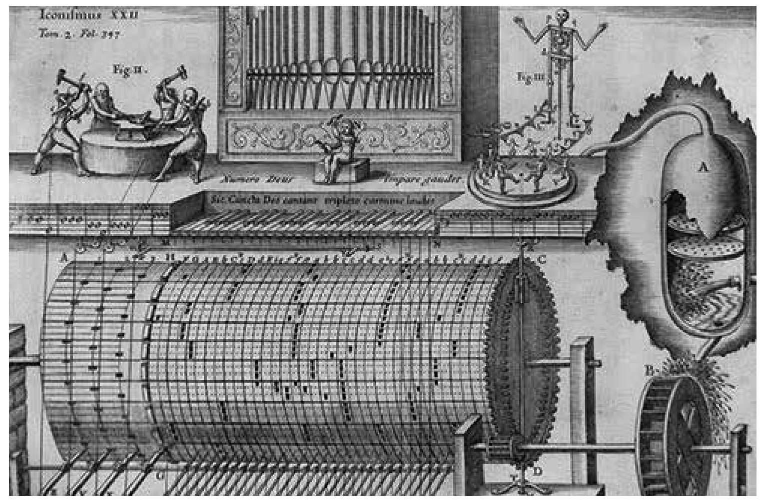


Figure 2.1. Athanasius Kircher's diagram of the automatic organ at the Quirinal Palace in Rome. According to Eggington, Kircher illustrated "accounts of unusual musical instruments that relied upon hidden sources of power. Built in 1598 this includes a mechanical representation of the legend in which Pythagoras visited the blacksmith's forge and discovered the laws governing musical pitch."[4] Reproduced from Athanasius Kircher, *Musurgia Universalis*, 1650, Vol. 2 (Af-x.10): plate between pages 346 & 347.

According to Zielinski, the evolution of media, the technological devices for hearing and seeing go back through thousands years of cultural and technological history of mankind. That, the history of media is non-linear, with un-realized potential uses of technology and these are spaces of action for attempts to connect what is separated.[3]

The museum itself belongs to a deep time of media.[5] That is if we start to rethink what even constitutes a media infrastructure, and by re-examining urban and architectural history, their material nature that is so critical to the sustenance and propagation of culture and knowledge. In Deep Time of Media Infrastructure, Shannon Mattern says that the examination of the history of the evolution of our urban media infrastructures shows technical networks of voice, writing and later on print that were the prime factors of making cities and its institutions communicative spaces.[6] It shows "how urban surfaces, volumes, and voids have functioned as sounding boards and resonance chambers for mediation and as transmission media themselves."[7] Accordingly, our media histories [including that of the museum] are deeply 'networked' with our urban and architectural histories [and futures] and in many cases, these cultural and technological forms are mutually constructed.[8]

The museum is also a material construct, a media infrastructure by itself, as an evolving materialization of the blooming and entanglement of culture, sciences and arts and as such a remediated institution dating from our cultural past. We could consider the museum as a cultural institution, a product of our urban environment that according to Mumford is "the area for local intercourse that engenders the need for combination and co-operation, communication and communion"[9] Its media history is entwined with our cities, their streets, the sewers, the power systems and the infrastructure lying underneath. It carries within it residues of past media technologies that are further remediated to the present and still active in the cultural process, therefore extant not only as elements of the past but effective elements of the present.[10] Bolter and Grusin call this phenomena 'Remediation' as "the representation of one medium in another and as a defining characteristic of new digital media." By this approach, remediation happens in a museum, by which new digital media exists simultaneously with the existing building and artifact collections, exist in a state of multiplicity or hypermediacy, trying to interpret and represent the old in newer ways.[11] Thus, "when we look at our media histories through our cities and museums, that can also be found in photography, film, television and print, we observe a layering, or resounding, of media epochs."[12] Such an approach opens up the possibilities for studying the materiality of museums. Therefore, considering the development of the museum and studying its media history over deep time and space could offer a clearer sense of how it might be transformed.

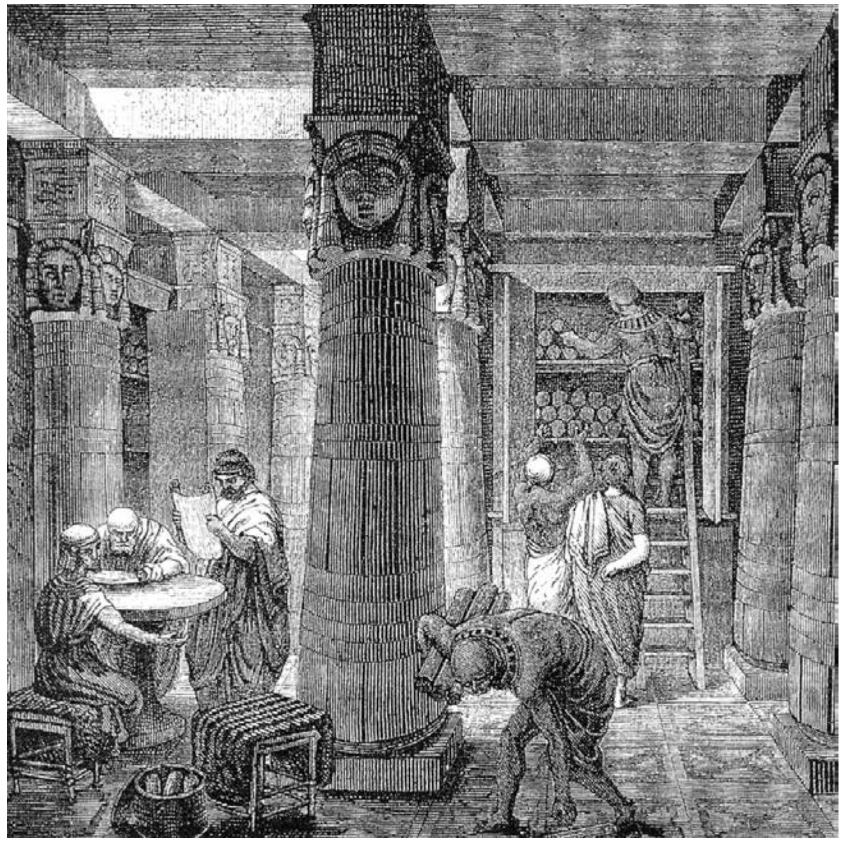


Fig. 2.2. Artistic Rendering of the Library of Alexandria. Illustration by O. Von Corven, Tolzmann, Don Heinrich, Alfred Hessel and Reuben Peiss. The Memory of Mankind. New Castle, DE: Oak Knoll Press, 2001, distributed under a CC-PD license.

According to Diaz-Kommonen, what is constantly referred to as the first museum, the 'Musaeum' or the 'Mouseion' or the 'Temple of the Muses' at Alexandria, ancient Egypt is dated to the reign of Ptolemy I Soter in the third century BC, was in fact a place for discussion and communication (voice) of knowledge. [13]The Alexandrine Museum, embodied the notion of a dynamic institution that fused diverse cultural currents, and evoked the glory of the past while at the same time bringing it into the present. "Its scholars' deliberate efforts to compile and critically analyze the knowledge of their day allowed for the first systematic, long- term research by dedicated specialists in the new fields of science… the methods of research, study, and information storage and organization developed in the Library are much the same as those used today, but just as the medium of linear scrolls gave way to books in its halls, we now are watching the transformation from books to multilayered documents in the electronic medium."[14]

While the Library of Alexandria functioned as a physical storehouse of knowledge in the form of over half a million texts and scrolls [and not physical objects], the 'Mouseion' was a materially-constructed place, attached to the Library dedicated to the assembly and discussion for scholars, artists and philosophers who were engaged in the study of science (for instance, medicine, mathematics, astronomy) and in the study of Literature (editing the major Greek texts such as Homer).[15] The 'Mouseion' featured a roofed walkway, an arcade of seats, and a communal dining room where scholars routinely ate and shared ideas. The building was equipped with private study rooms, residential quarters, lecture halls, and theaters.[16] Thus, the 'Mouseion' as an early cultural institution was supported by a vast and intricate architecture and infrastructure of the Library of Alexandria, and together the pair functioned as a storehouse of knowledge from Greek cultural heritage.

According to Peter Davis, the early history of museums is closely associated with a growing interest in the natural and cultural environment. But of course, not as in-situ understanding and conservation of the environment, but rather a history of collecting of animals, plants and fossils in order to try to understand the diversity of nature. "To read the book of nature as a vast collection of signs was habitual among

Fig. 2.3. The Studiolo of Francisco I in Palazzo Vecchio de Florencia. Photograph by Giorgio Vasari, distributed under a CC-PD license.[17]

natural philosophers and artists of this period."[18] Additionally, the collection of artifacts that represented past cultures or other world cultures, was already an established practice during the Renaissance, and may have its earliest origins in sixteenth century Italy.[19]

At the universities of Pisa, Padua and Bologna, and in the Italian courts, academies and pharmacies, nature was subjected to an intense enquiry.[20] Here, Findlen mentions that collecting and interrogation of nature were conducted by naturalists such as Ulisse Aldrovandi (1522-1605) and Athanasius Kircher (1602-1680), resulting in new attitudes towards nature, as a collectible entity and generating new techniques of investigation.[21]

Kircher's media interrogations were housed in the Museo Kircherianum, which the Jesuits established in the Collegium Romanum.[22] According to Zielinski, this Museo was –

> *"sought out by learned visitors to Rome from all over the world, the museum was one of the city's most popular attractions in the second half of the seventeenth century. Set up after the manner of a wunderkammer (cabinet of wonders), the museum exhibited curios from faraway places, which had been sent to Kircher or brought back by his correspondents, and his own constructed artifacts: fossils, books, maps, mathematical and astronomical instruments, mechanical and hydraulic clocks……the concept of technology that Kircher elaborated and presented here was, on a complex level, entirely characteristic of natural magic."*[23]

During this time, the Medici Palace, considered, as "the first museum of Europe" was constituted for the accumulation of rare material things combined with the acquisition of rare natural and cultural artifacts from the voyages of discovery.[24] The vast palace was designed for productions of artificial contexts which were constructed to exhibit an imposing impression. Here, the production of scenarios was to create an imposing spectacle for private and exclusive inspection and not as an urban communicative space of voice and writing.[25]

By the eighteenth century, efforts were on to completely encapsulate the material world, enclose nature in a cabinet. Peter the Great in St. Petersburg had created his own personal 'universum' museum, as an attempt to understand the environment, a means of managing an explosion of material evidence about the world.[26] This later on took

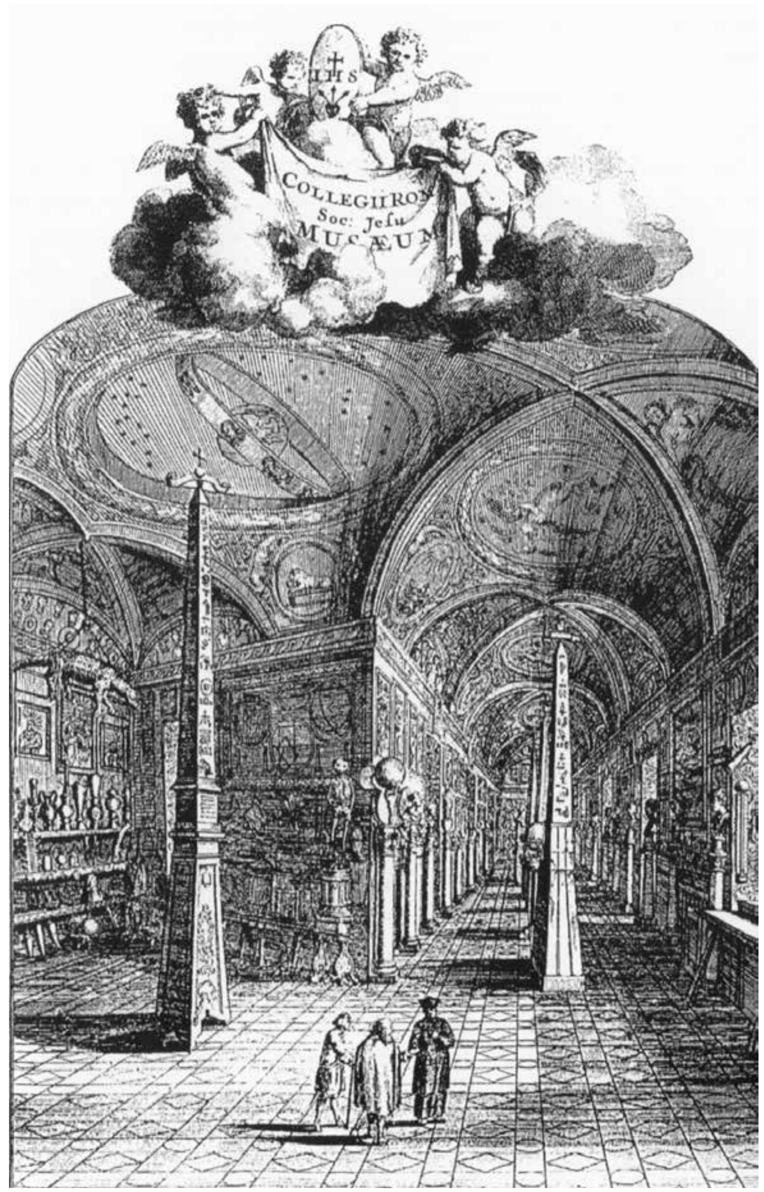


Figure 2.4. Museum Kircherianum (1679) at the Collegium Romanum. Book scan of Alexander Roos, *Alchemie & Mystik*, Köln: TASCHEN, 2007, distributed under a CC-PD license.

the form of a colossal building complex to house the ever growing collections as envisioned by Catherine the Great, that today is considered one of the largest museum infrastructure in the world.[27] From then on, collections building expanded monumentally, eventually becoming a major social phenomena of the late eighteenth and nineteenth centuries.[28]

According to Paula Young Lee, scholars in late eighteenth century France extracted the ideas that were to eventually lay the conceptual foundation for the creation of the modern museum.[29] The term 'museum' evoked the glory of ancient city of Alexandria, the cultivation of intellect supported by a monumental architecture. But, the essential Alexandrian principle of communication of knowledge through voice and writing was not applied. When in 1793 the French Revolutionary government accorded its newly available public collections of rare objects the name 'museum' in reference to the Alexandrian project, it was already associated as a part of the specialized vocabulary of archaeological and architectural terms.[30]

Davis says that the collecting practices of museums did not much alter during the later years of the nineteenth and the early twentieth centuries. Perhaps, the accent now was on improved cataloguing, classification and archiving methods. This was essentially directed towards a better understanding of the systematics and taxonomies of animals and plants,[31] and that was aimed at framing the material nature as a human-centered environment.[32] The appreciation for the built environment and infrastructure grew and museums were closely associated with the conservation and interpretation of our archaeological and architectural past.

Ernst says that the early nineteenth century also witnessed — "the invention of new ways of envisioning the past in literature, painting, and museums as an effect of lighting technologies (candlelight, gas lanterns, electric light), a new quality of cultural transfer was also introduced by electricity, as Gandy, among others, recognized."[33] Such as with the introduction of the top lighting at Grand Gallery at the Louvre , thus— "visions of the past became technologized through the conscious application of artificial light and eventually the aesthetics of top-lit galleries in museums became predominant." This can also be

Fig. 2.5. An early eighteenth-century German Schrank with a traditional display of corals at the Museum fur Naturkunde Berlin. Photograph by LoKiLech, distributed under a CC BY 3.0 license.

seen through the example of the Crystal Palace that is designed and built with clear transparency to let natural light to descend upon the art works: "indicates the degree to which visions of the past had become a technological function of lighting." Ernst argues that — "the rise of technological media displaced the traditional visual rhetoric of representations of history by reconfiguring its reality effects—a process that became almost tangible in museums."[34]

According to Michelle Henning the history of the modern museum in fact coincides with the history of modern recording media.[35] This happened in representation of history and science, especially through interactive science museums and galleries. That the — "media technologies of the later nineteenth century did not outmode the museum, rather they developed and enhanced it further." The aim of new media technologies was also to disseminate accumulated knowledge further in a modern mass society for educational purposes. The museum's relations with the audience thus changed toward democratization and increasing control through the use of these new technologies. Citing the example of Otto Neurath, his use of Isotypes at the Natural History Museum in London, Henning shows how he tried to invent systematic ways, dependent on media, by which information was made democratically available. The move was toward translating archival knowledge to the common people through museum as a media-form that was based on media-based representation and 'experience'.[36]

Fig. 2.6. *Left*, The San Francisco Exploratorium, 1969; *right*, the exhibition of Cybernetic Serendipity, 1968.

Interactive science exhibits in the 1960s and 70s also emphasized the visitor as an active participant and brought in the visitor into the museum through 'interactivity' of exhibits.[37] Interactivity became a dominant model by which museums could be democratic and also visitors could be turned into informed technological citizens. Henning says, that the San Francisco Exploratorium was a prime example where interactive devices shifted the focus of the museum away from objects toward demonstration of scientific principles, processes and phemomena.[38] Here, the artifacts acted merely as supporting roles to the overall narrative of the exhibition.

One exhibition that pushed the Exploratorium in a new mediatic direction was the Cybernetic Serendipity — The Computer and the Arts, curated by Jasia Reichardt.[39] The exhibition was about the relationships between the animal/human and the machine, and between technology and creativity. Included were, products of corporations, research labs, computer artists, and other contemporary artists who worked with technology. This presented —"media machines as an agreeable collaborator rather than a mere tool or an enemy. After all the machine was the extension of humans, and a complement to human intelligence."[40] Here, a key element was the importance of distraction, and the chance encounter…..linking to the ancient custom of curiosity or serendipitous discoveries. Henning says that the exhibition suggested a unique approach to interactivity: that favored unanticipated effects, that encouraged scientists, artists and engineers to have fun, experiment and fraternize with the audience. Thus with this, a very different model of the museum audience was presented where visitors transformed into technological citizens.

Since, science museums have kept redefining the technological approaches to exhibition practices and the representation of arts and culture. The museum thus increasingly became like other media, severing connection with artifacts in favor of representations. Computer displays and screens whose operations were invisible and existed in expert territory, came to serve up information about artifacts, offering 'interactivity', with a greater emphasis on the audience's own perceptions and body. According to Zielinski, already in the seventeenth century, Kircher's technical artifacts and their specific arrangements [in the Museo Kircherianum], "established a tradition of visual apparatus that was a dominant and effective model….by which media machines were designed and built in such a way that their functioning mechanisms remained a mystery to the audience."[41] This is similar to how today — "technological media have to make their recipient forget their technical operation at the machine-to-human interface in order to create the illusion of pure content: only at a moment of technological breakdown will the medium become visible."[42]

The decade of 1960s also witnessed a range of environmental disasters, the emergence of Environmentalism and the growing unrest throughout the museum world.[43] By then, museums had to start responding to the emerging ideas of sustainability, be more receptive to the wise use of environmental resources.[44] According to Davis, this led to not just exhibiting objects, but of interpreting them and led to the rise of interpretive media where the museum experience became eventually augmented by media technologies. Modern expositions (upon which museum exhibitions were planned), were thematized technologically, the idea of progress driven via the projection of a line between past, present and future technologies, paying less attention to what they displayed than to the means of representation.[45] Thus the means and methods, the machinery of displaying were accorded a greater emphasis, and became self-referring. This tendency toward representation through other media, especially computers was widely adopted throughout museums since the 1990s. In this regard, on the topic of the virtual museum, Huhtamo traces this 'virtual' turn of museums to the emergence of exhibition design as a new medium within the avant-garde art movements of the early 20th century; especially in the works of artist-designers such as László Moholy-Nagy, El Lissitzky, Herbert Bayer and Frederick Kiesler, —" whose works often raise issues like storage and erasure, memory and forgetting, revealing and hiding, the physical and the virtual."[46] Exhibition design changed how museums operated, not simply by the display of individual artifacts, but combining them with media technologies as a total environment in the —"manufacture of experience." [47]

Today, with the advent of 'cloud' hosting on remote servers in data centers, museums have started to store away digitized assets and collections and allow access through local networks of computers on the exhibition floor. Increasingly, the museum has become dependent on an intricate and vast body of media infrastructure whose operations currently are incomprehensible and the hardware hidden from view from the audience. The material structure and organization of the museum media infrastructure has gradually evolved to support the media-intensive representation of artifacts rather than toward the

Fig. 2.7. A mixed-media wall of screens and artifacts at the Natural History Museum. All copyrights belong to the Natural History Museum.

exchange of knowledge and spaces for communication. Infrastructures needed for a museum for its daily immaterial practices have expanded in materiality in the form of media and computing hardware, content distribution and storage systems. These media infrastructures in turn are linked to substantial energy footprints and the use of natural resources.

ENTANGLEMENTS OF MUSEUM INFRASTRUCTURE 2.3

According to Parks, media infrastructures are not just the product of the contemporary technological formations of our age, rather they are also as products and entanglements of energy, natural resources and human labor.[48] This entanglement has today intensified in the development of digital media and in the various fields around media and infrastructure.[49] The entanglement of museum and energy use is best seen in the convergence of 'hard' and 'soft' media infrastructure, when insulated walls carry cables of data. Or in form of heat dissipated from computer hardware inside designed spaces that are offset by air conditioning infrastructures.[50] Currently, it is impossible to completely separate the digital from the building systems. The museum has become one single media entity where the walls, the exterior skin, Heating Air-Conditioning & Ventilation (HVAC) systems and media technology are all connected, can be monitored and controlled by operational interfaces. They are not only interlinked by blackboxed media devices and processes with high embodied energy but also depend upon each other for smooth functioning of the museum system. Sure, the bricks might be on the lowest rung of the media infrastructure, sitting uncommunicative, yet they are essential banks of heat, cold and moisture that affects the building skin containing the assortment of critical digital cables and sensors and in turn the energy use of the museum. The blackboxed hard and soft media infrastructure continue to influence and affect each other, such that the energetic and technological outcomes of the museum are in a perpetual loop of mutual shaping and construction.

MUSEUMS AND ENERGY USE 2.3.1

The measure of energy just like the museum's media infrastructure is usually difficult to visualize. What is usually offered by the energy providers is represented in numbers and measured units of kilo watt hours (kWh) that is hard to comprehend without having knowledge

Fig. 2.8. *Top*, The Immersion Room at the Cooper Hewitt Smithsonian Design Museum. Visitors can browse collections on a multitouch table and then project selections to the surrounding walls. Photograph courtesy of Cooper Hewitt Smithsonian Design Museum. All copyrights belong to CHSDM; *bottom*, recycling of e-waste, breaking into a PC for recycling of its internal parts in Ghana.[51]

in the specifics of the electricity market and power generation. The measuring instruments, the electricity meters are themselves technological blackboxes buried deep in the infrastructure hidden from view or only accessible by authorized personnel[52]. Rupp shows —"how lacking accessible technical knowledge for thinking about energy and its uses, New Yorkers turn to multiple and hybrid images—magical, spiritual, corporeal, social, political as well as technical—to explain the forces that enable their everyday lives."[53] Energy is not only a material force but also embedded in various societal contexts. It has a multiplicity of meanings and understandings and as such difficult to map. It is embedded with information much more than what the kWh conveys. Despite the increasing need to visualize energy footprints and costs, the energy use of components and operations across the museum infrastructure are represented merely by a simple monthly statistic: a monthly meter reading from a single metering source. Thus it is never possible to explore a wide-ranging analytics of the energy readings of the various parts of the museum's media infrastructure. The flow of content and its energy use within the museum infrastructure and beyond its infrastructure is also not thoroughly studied nor mapped. Much of this is energy consuming and more so when the underlying structure and processes are invisible or hidden.

Digital Media is unthinkable without the energy needed to run and produce them.[54] According to Cubitt, "when we add to the energy required by server farms to the demands of domestic and office equipment usage, and to them the energy costs of extracting materials, manufacturing digital equipment and recycling them, we begin to understand the scale of the environmental footprint proper to digital media."[55] This pertains especially to museums such as the Cooper Hewitt or the Victoria and Albert where digital media is abundant and ubiquitous. An examination of Victoria and Albert Museum's carbon footprint uncovers a large percentage from utilities that is lighting, heating and power systems.[56] These utilities are ultimately derived from local power suppliers creating energy through oil and natural gas that are all fossil fuels. The energy reports of Cooper Hewitt Smithsonian Design Museum (as will be examined in Chapter 3) show an annual consumption of 7,73 kWh/sqft. For 17 000 sqft, this amounts to 131 410 kWh or 131,41 MWh (megawatt-hour). What do these numbers mean to the museum audience or to the museum personnel themselves? What information do they carry? Their impact on the materiality of the media infrastructure of the museum is quite difficult to comprehend. Many reports and studies are available on the expanded digital media strategies, but not many studies can be found on the energy consumption of museums and their environmental impacts.

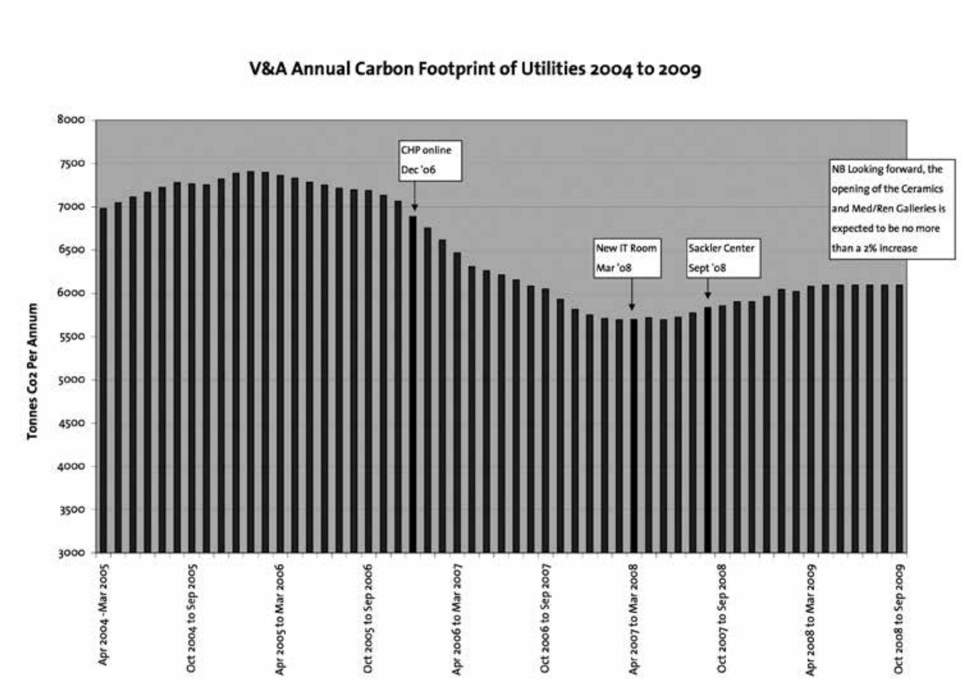


Fig. 2.9. Victoria and Albert Museum, Annual Carbon Footprint of Utilities 2004 to 2009. Photograph courtesy of Victoria and Albert Museum. All copyrights belong to Victoria and Albert Museum.

Today, museums use energy-intensive media technologies in their daily practices that go above and beyond the museum's earlier traditional energy requirements for the simple tasks of collections management, display and maintenance. These can be seen at various scales, from the scanner in the digitization lab to the server in the data center, from the multitouch media exhibit on the museum floor to the climatically sealed compartments in the conservation storage. The media infrastructure of the museum is supported by the building skin and the essential mechanical systems that are the highest energy consuming components of the museum.[57] Most of this infrastructure and operations are concealed behind walls and basements just like the electricity meter hidden in the cellar of an apartment building. These components and spaces depend on electricity supply and mechanical air conditioning systems, and in certain cases without a supply break. Thus, museums have a heavy demand for resources resulting in significant emissions. The average energy intensity of a museum is 15.7 kWh/visit. This energy consumption associated with emissions contribute to global warming valued at 2.34 kg of CO_2 per visit.[58]

MUSEUMS AND EMBODIED ENERGY (EMERGY) 2.3.2

Embodied Energy or Emergy is an often overlooked phenomena in considering the energetic impact of infrastructures. Scienceman refers to emergy as energy memory. Brown and Herendeen say that when a system is evaluated in solar emergy, the quantities represented are the 'memory' of the solar energy used to make it. As a result, the quantities are not energy and do not behave like energy.[59]

According to Raghavan and Ma, embodied energy (Emergy) is the energy required to build the devices and infrastructure that comprise the Internet[60], – "the calculation of emergy is a complex process that involves considering the energy used during the manufacture of devices, the contribution from components and materials of the device, and recursively the emergy of those components and materials." Every device and object has its own dimensions, material content, methods of making, and use, thus making them owners of a quantifiable emergy.

Brown and Herendeen say that without understanding emergy, and only focusing on the energy use of infrastructures, we cannot come to an objective calculation of the footprint of a device or an artifact.[61] Additionally, "to derive emergy of a resource or commodity, it is necessary to trace back through all the resources and energy that are used to produce it and express them in the amount of energy that went into their production."[62]

TABLE 2.1 Wall-socket power and embodied power estimates for Internet devices and infrastructure. Source: Raghavan and Ma, "The Energy And Emergy Of The Internet," 2011.

CATEGORY	WALL-SOCKET POWER	WALL-SOCKET DUTY CYCLE	TOTAL POWER (MIN)		TOTAL POWER (MAX)	
			Wall-socket	Embodied	Wall-socket	Embod-ied
Desktops	150 W	0.5	28.1 GW	22.3 GW	53.4 GW	42.3 GW
Laptops	40 W	0.5	11.3 GW	26.7 GW	15.0 GW	35.6 GW
Cloud	450 W	1.0	18.0 GW	2.1 GW	22.5 GW	2.6 GW
Smartphones	1W	0.5	0.13 GW	4.0 GW	0.45 GW	14.3 GW
Servers	375 W	1.0	18.8 GW	2.6 GW	35.6 GW	5.0 GW
Routers	5 kW	1.0	4.5 GW	0.48 GW	5.0 GW	0.53 GW
Wi-Fi/LAN	20 W	1.0	1.5 GW	0.80 GW	2.0 GW	1.1 GW
Cell Towers	3 kW	1.0	1.5 GW	0.16 GW	7.5 GW	0.80 GW
Telecom Switches	75 kW	1.0	0 GW	0 GW	1.4 GW	0.06 GW
Fiber Optics	0W	0	0 GW	23.8 GW	0 GW	42.8 GW
Copper	0W	0	0 GW	3.7 GW	0 GW	18.5 GW
Total for Internet			84 GW	87 GW	143 GW	164 GW
			170 GW		307 GW	

Today, museum collections are gradually being migrated to remote data centers as terabytes of digital heritage. Gabrys says that, – "the migration of archived materials to digital formats has shortened the life of most museum objects, tied as they are to the life of electronic data….these newly digitized objects require a continual transference, updating, and migration to newer formats in order not to dissolve into the inaccessible static of obsolete electronic data."[63] A vast amount of media infrastructure goes into the custodianship of digital heritage, much more than what is needed to store artifacts in museum cellars and storage spaces. Not only there is the emergy of the digitization infrastructure needed to digitize heritage, but also the emergy of storage devices that are needed to store the digitized data. Furthermore, computer displays, screens, multitouch devices needed to interact with this digitized heritage are all embodied with energy and material resources.

Take for examples, the digital collections of a museum that could be stored into a one terabyte external hard drive. Or, one could also place them into a Cloud hosting service. The digital collections of the Cooper Hewitt Smithsonian Design Museum easily fits within both. It would contain over 273 404 object records and 90 012 image records amounting to a mere 527 Gigabytes. The power consumption would be negligible, about 0.009 kWh for the external hard drive at running mode. For the cloud service it is much more fine grained and would be much harder to quantify. Yet, those gigabytes currently stored in a Data Center of the Smithsonian have a power consumption of 20 676 kWh annually and un-verified amount of emergy.[64] Surely, the emergy of an external hard drive must be less than that of an entire data center and the media infrastructure required to support the flow of digital content. We shall explore this theme further in Chapter 3.

It is widely acknowledged that calculating emergy is a challenge. Tracing down the various material constituents of a media device to their mines, to their factories, and to their labor amounts to a vast enterprise[65]. In the case of the museum, it would require not only accounting for the media infrastructure, but also the emergetic collections of the museum. The energy footprint of a museum would then include the energy needed to host this emergetic content and the emergy of the various components of the media infrastructure. And by doing so, the emergy required to build the black-boxed devices and collections infrastructure could be related to the flow of content within the museum.

2.3.3 MUSEUMS AND BLACK BOXES

A black box is a device or system whose inputs (actions) and outputs (reactions) are observable, but its internal workings are usually concealed. A black box could also refer to any media device such as a computer or a calculator whose internal circuitry is hidden behind an interface, or a multitouch table, beyond whose touch surface lies 'expert' territory (serviceable only by the manufacturer). This concealment of inner workings of media has been a typical feature characteristic of the last few decades of information technology cultures.

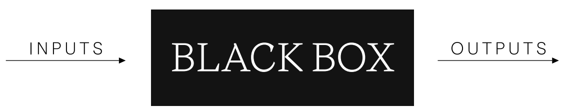


Fig. 2.10. A Black Box.

Hertz and Parikka say that —"from a design perspective, the technology is intentionally created to render the mechanism invisible and usable as a single, punctualized object." Accordingly, "there is not simply one black box, instead, one box hides a multitude of other black boxes that work in interaction, in various roles, in differing durations."[66] Thus, Latour says that the mediating role of techniques cannot be easily measured since it is subject to blackboxing, that makes the joint production of actors and artifacts entirely opaque.[67] He uses the example of an overhead projector, which is when broken and thus opened, exposes its multiple individual parts each its own multiple black-boxes and actants. Gabrys argues that it is software that ensures that the lid stays on the black box of electronics, and our only window into these mysterious devices is through the interface, which can effectively obscure the workings of this technology. Thus, attention is directed toward the effectivity and functionality of these devices and not toward their resources, labor, and environmental effects…..."[68]

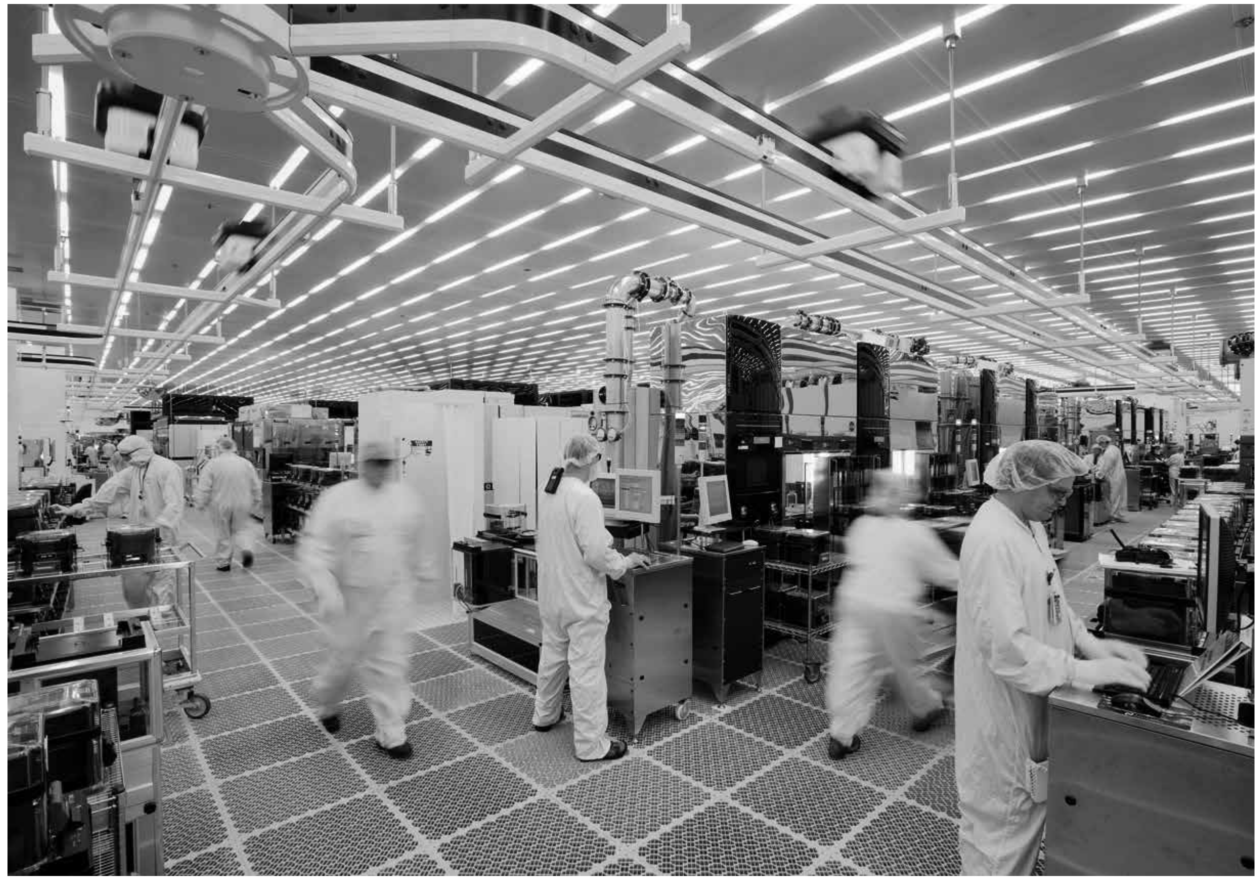
The museum is in itself a black box besides being a repository of black boxes. Most of the media infrastructure of the museum, through which the content flows, is an assortment of energy-intensive black-boxed proprietary media technologies starting from the rack server in the data center to the multitouch screen on the museum floor. The digitization hardware, the large format 2D and 3D scanners are patented technologies and serviced only by the manufacturers themselves. The media exhibits, the multitouch screens, projections and displays are all media technologies sealed away via patents, licenses and contracts, the underlying supporting cables and electric power included. The concealment of media infrastructure spans through multiple departments, practices and personnel, black-boxed, compartmentalized and oblivious to each other. Even, the data centers where the digital collections are stored are opaque unknown entities, their infrastructures remain black-boxed and even so, the workings of cloud computing service providers are secretive and information about the internal processes are not easily available.[69]

MUSEUMS AND ECOLOGICAL MEDIA 2.3.4

Today, sustainability is a much contested term, a complex imbroglio of science, technology, sociology, economics, politics and nature.[70] According to Rice, " the term 'sustainable' has rapidly become a ubiquitous prefix for many contemporary issues, professions and disciplines, such that understanding sustainability cannot involve separating out knowledge, power, science or nature; as they are all tied together into a collective concept." How could we outline a contextual and critical engagement with 'sustainability' beyond just electricity meter readings and carbon dioxide emissions of the museum? How to examine the museum infrastructure beyond an already punctualized sustainability discourse?[71]

The generally accepted definition says that 'sustainability' means 'meeting the needs of the present without compromising the ability of future generations to meet their own needs.'[72] Some have indicated "the need for sustainability to include a social and environmental component of justice."[73] Therefore, "it should be possible to extract resources with attention to environmental consequences, but unless it's done in ways that ensure the planet remains healthy enough to support human life, where all people enjoy peace, health and food security, can it really be called sustainable?[74]" The historic context of the term "sustainability" in a way "links robust economic development with inventive resource management, and the philosophy of sustainability is rooted in how humans manage and maintain resources like electricity, energy and water for future use by all cultures without compromising ecological diversity."[75]

Media has always been rooted in the environment. Parikka says that media technologies arise from the geologies of the earth, and there they eventually return.[77] Accordingly —"To talk of sustainable media begs the question what do we mean by "sustainable" but also what do we mean by "media"? Do we refer to media as communication, discourses, patterns of meaning created, circulated, and controlled in political economic contexts? Do we think of media as the work of mediation between people?"……As a question of material settings— "media is not just as a cultural reality of communication but at the same time, a material reality of technologies that, to put it bluntly, are made of something and demand energy."[78] In this context, Gabrys argues that we need to consider in the question of sustainable media— "of what lies beyond the screen, of how hardware unfolds into wider ecologies of media devices, and of how electronic waste may evidence the complex ways in which media are material and environmental, despite our tendency to overlook these interconnected infrastructures, supports, and resources."[79]



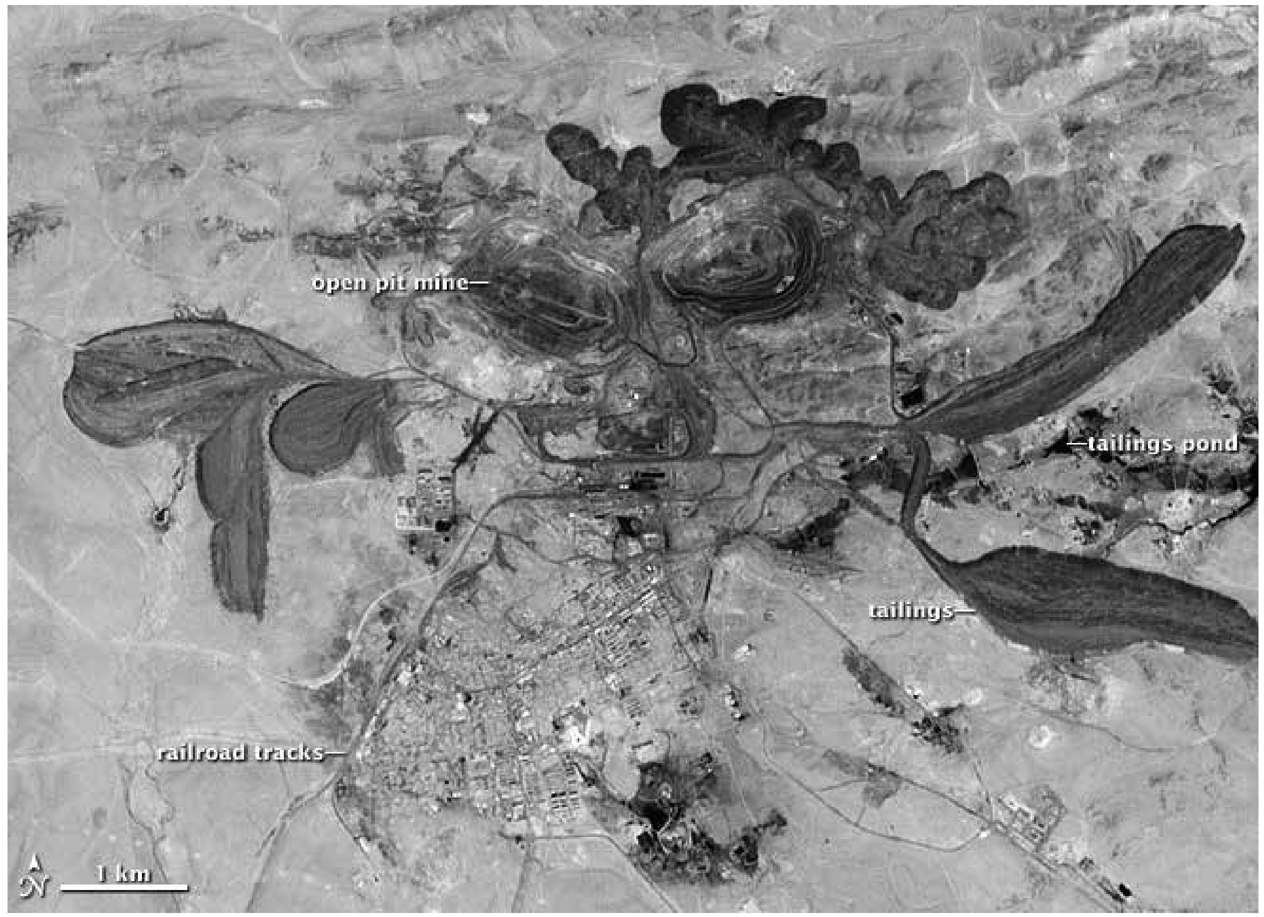


Fig. 2.11. *Top*, A silicon wafer fabrication facility at Texas Instruments. Photo by Jeffrey Stevensen. All copyrights belong to Jeffrey Stevensen; *bottom*, the Bayan Obo Mining District, Inner Mongolia, China holds the world's largest deposits of Rare Earth Elements (REE) such as Europium (Eu) used in media exhibit screens and Neodymium for magnets used in sound devices. The REE extraction process is hazardous, toxic and has resulted in long-term damage to the environment.[76] Photography by NASA Earth Observatory, distributed under a Public Domain license.

The idealistic view of nature impedes a proper relationship with the earth and its life forms, and the concept of what constitutes the 'environment' itself needs to be rethought.[80] What in fact constitutes "the reproduction of data that underpins human communication happens on levels that are material and inherently connected to issues of ecology and the environment."[81] To talk about environmental dangers of oil spills, toxic lakes, might appear not to be connected to the materiality of media, yet it offers an alternative to the traditional sustainability discourse.[82] Instead of 'sustainable' media, a collective, vague and contested concept (that threatens to derail the effect of media on the environment) we should be aiming for 'ecological' media in museums. Here, a materialist approach to media infrastructure is apt, since the material (metals, energy, water) of media is the link between environment and technology. The imperative of being 'ecological' also impels us to contemplate the idea of the "deep museum", where we not only reflect on the condition of the environment around us, but also illuminate the issues that are fundamental to our future.[83]

2.4 RESEARCH THESIS

2.4.1 PROBLEM

The dissertation contends that the museum system and the flow of content within and beyond its infrastructure is not well studied with regards to energy use. Especially, its media infrastructures at various scales and related energy use are not coherently mapped. The media strategies vary from institution to institution and there are no set rules or frameworks for energy saving. Black-boxed 'sustainable' strategies, and proprietary green certifications are being used by museums at the exclusion of wider ecological, equitable, social and economic concerns.[84]

The ad-hoc and intermittent introduction of emerging digital media into the museum has its own energy consequences. It has caused a layering of distribution technologies superimposed on older incompatible infrastructures and practices. New technologies are installed without an overall concept and live alongside the old, and in some cases established without concern for energy use nor obsolescence. In this case, older media technologies live alongside the new, resulting in separate black-boxes and could be the reason for mixed messages. A conflict between older energy inefficient technologies and newer could lead to unnecessary energy consumption. The simultaneous existence of various scales of media infrastructures and operations of the museum such as cloud collections, digitization and media exhibits infrastructure need constant coordination, vigilance and maintenance. Here, resources and labor required for maintenance and repair of equipment and components may not often be calculated into the museum's long term strategies.[85]

The media infrastructure supported by the building skin and the essential mechanical systems are the highest energy consuming components of the museum. Most of this infrastructure and operations lie hidden, concealed behind walls, and in basements and suburban storage facilities beyond the public gaze, just as most museological practices are today still performed in-house. Several proprietary benchmarks and certifications exist that measure the 'sustainability' of museum infrastructures such as United States Green Building Council (USGBC)'s Leadership in Energy and Environment (LEED) or UK's Building Research Establishment Environmental Assessment Methodology (BREEAM).[86] These are ratings based on a set of fixed criteria for ecologically friendly construction.[87] Here, 'sustainability' has been approached through a stabilized and restricted set of indicators (i.e. black-boxes) related to energy use, through building a meta-narrative that is now a standardized framework, where carbon dioxide has become the chief spokesman.[88] Today, studies show that 28–35% of LEED buildings use more energy than their conventional counterparts.[89]

Thus, to investigate the museum infrastructure and its entanglement with energy and the environment requires an alternative approach. According to Star and Ruhleder, it involves "changing common views and metaphors on infrastructure: from transparency to visibility, from substrate to substance, from short term to long term."[90] We need to approach the Museum as a medium steeped in materiality, as an infrastructural assemblage, as a world described by German media theorists Friedrich Kittler and Wolfgang Ernst as "a network of concrete, material, physical and physiological apparatuses and their interconnections."[91] We not only look at the present media ecologies but also what has come through the past to the present. Here, we need to focus on the basic material structures of the technologies that support infrastructure themselves and the changes they introduce into the culture, in other words, "not to understand media (infrastructures) but rather to document their emergence so as to make visible the material structures of communication (content movement)."[92] Without understanding the invisible materiality of its own infrastructure, a museum cannot effectively enact strategies in the future to chart its technological course in an ecological manner. This involves not only technologies that could be made available for conservation, digitization and collections management but also what Parks and Mattern define as the 'un-communicative' 'bricks and mortar' material infrastructure of the museum.[93]

How much energy is required to construct, run, and maintain the museum? What are the resource demands of its media infrastructure? How does the distribution and flow of digital heritage content affect the energy consumption? The problem of this dissertation is how to develop design methods for incorporating ecological media infrastructures to serve museums. Here, being critical about 'sustainability' is also a significant goal. Our approach is to not restrict ourselves in the carbon dioxide discourse, but to look beyond. This research seeks ways to judiciously design infrastructures in a way that supports and augments ecological museum practices.

2.4.2 RESEARCH QUESTIONS

The challenge of building a design framework for ecological media infrastructuring for museums presents us with three primary research questions that drive this dissertation.

First, *What domains of media infrastructures of the museum are energy consuming?* What is the emergy (embodied energy) of these infrastructures? Are these visible or invisible? The earlier analysis of infrastructure as related to energy use revealed especially how the movement of content within and beyond the infrastructure of the museum is not well studied with regards to energy use. It is also vital to understand the museum's media infrastructures at various scales and to excavate and enumerate them by energy use and emergy. This excavation allows us to peek into the weak links and broken connections between components and operations, emergy and the resulting energy consumption.

Thus drawing and understanding the energy-emergy-infrastructural map of the museum gives rise to the next research question: *What practices could help develop alternative media infrastructure that is ecological?* The question is addressed by designing infrastructural interventions (research objects) within and without the museum walls that could present alternatives to the museum itself. The goal is to discover new sets of methodologies by which these design interventions would be made and operated. An infrastructural energy evaluation of the interventions would then either justify or negate those discovered methods.

Finally after identifying areas of shortcomings and benefits learned from the excavation of the museum system and the design interventions, will give rise to our final research question*: What design guidelines (framework) could assist museums to build media infrastructures with low environmental impact?* The framework would necessitate iterative testings and evaluations within an institution to provide deeper insight.

THESIS 2.4.3

Excavating the energy-consuming infrastructures of the museum and designing alternative systems could inform a design framework for building ecological media infrastructures.

This design framework would define the scope, develop a terminology specific to its analysis, and provide critical considerations to guide the development of media infrastructures. The framework also seeks to outline a set of tools and techniques that would allow institutions such as museums and cultural heritage institutions to better design and deploy critical and ecological media infrastructures.

2.5 RESEARCH METHODOLOGY

As we have seen, the study approaches the museum as an infrastructural assemblage, as an energy-intensive medium steeped in materiality. Earlier in this chapter, in 2.2, we have briefly encountered the 'deep time' of the museum infrastructure which served as an excavation into the museum system. This was followed by an analysis in 2.3, of the contemporary entanglements of museum infrastructure with energy use, emergy, black boxes and ecological issues. These comprise our first steps towards the investigation of the museum as a medium and media infrastructure.The study then has identified the problem of the energy-intensive media infrastructures of the museum as a research space, along with research questions and a thesis. The research questions lead us now to enquire about what methods could be adopted to answer them.

The study being multi-disciplinary and practice-based, itself is heterogeneous and entangled in various methods arising out of museum studies, architecture, design, media studies, energy and infrastructure studies. Methods were adopted, modified (even abandoned) and were taken forward during the course of the dissertation as and when problems, situations and circumstances deemed it necessary. Studying the infrastructure of the museum requires a drawing together of methods, since no one method is sufficient enough to approach its complexity that is an assemblage of technological development. The layering of old and new media, black-boxed systems, distribution technologies and energy-intensive hardware superimposed on older and sometimes incompatible infrastructures and practices makes the museum a media monument by itself.

This monument of media materiality, according to media theorist Wolfgang Ernst, begs an archaeology— a methodological preference for rejecting the projection of generalized theories in favor of precise case studies[94], that "aims to avoid prematurely interpreting archival or archaeological evidence as documents of history, but rather isolates this data into discrete series in order to rearrange them and open them for different configurations."[95] Ernst, elaborating on the nature of tools needed for investigating media says that since— "our media perform digital signal processing, our media theory tools need to be able to be specific enough to understand that technicality. Technical media concern modulation of the world of physics and engineering…[..]….we need to incorporate new scientific tools into our archival and analysis work."[96]

Ernst's methods to examine media reflects his predecessor, media thinker Friedrich Kittler. According to Kittler, "archeologies of the present [such as the contemporary museum] must take into account data storage, transmission, and calculation in technological media."[97] Thus, Kittler focuses on the hardware of media technologies, and on the conditions and possibilities to which they give rise. He proposes "the impossibility of understanding media as technologies, for technologies are said to create the conditions under which understanding, or interpretive activity more generally, may take place, rather than vice versa, therefore any medium or channel of communication is a material technology, and thus cannot be understood in an interpretive sense."[98] Thus, Kittler seeks not to understand media but rather to document the structures of communication that technology both introduces and makes possible. The method here is deeply materialist in orientation by moving from a description of technology to questions of meaning rather than vice versa.[99]

In this context, Parikka has recently wondered whether Kittler's materialist media methodology could be used — "to investigate the relevance of materiality for environmentally aimed media theory."[100] How his work could give rise to further variations on the theme of media ecology: issues of waste, resources, and the mineral materiality of media technological culture that persist in terms of their role in global media industries of production and discarding of technologies.[101] And, hence direct attention to the concrete connections media as technology has to natural resources or what Parikka calls —"non-mediatic media materialism". Thus, efforts could be made — "to radicalize Kittler's media historical methodology and push media studies out from its sole focus on media, to the world of chemicals and materials, and even energy consumption?"

Cubitt's Finite Media provides a path forward, as it examines the various materialities of media, including global information networks, energy production, energy markets, mining and manufacture, in other words, "the deep dependence of contemporary media on energy and materials."[102] According to him, —"non-human mediations raise with even greater urgency the question of mediation itself, the processes that mediate between populations and environments, and in which environments, it now appears, play a significant role." This approach is also in a sense digging backwards, since we are forced to trace back the rise of mediation from matter of the earth itself.

How can we focus on the materialities of the museum system? Perhaps, "an examination of materialities of information must engage with information systems not simply as metaphors of virtuality but as historically and geographically specific configurations of technology and practice."[103] This requires an attentiveness to not just toward infrastructure but also to the flow of information through the infrastructure,[104] it also requires an engagement with computational objects and processes that make up the technological landscape.[105] Maybe now as Galloway says, "we must also descend into the somewhat immaterial technology of modern-day computing, and examine the formal qualities of the machines that constitute the factory loom and industrial Colossus of our age."[106]

This dissertation, with its excavation of the museum insists both on the material nature of its enterprise that not only media are always articulated in material, but also in non-narrative frameworks whether technical media or algorithmic.[107] In a sense we are exploring two sets of materialities embedded in the museum infrastructure, one that is expressed in tangible devices (hard) and the other that exists in computing languages (soft), that negotiates digital content.[108]

Thus, to try to understand the energy implications of the museum we need to look at it from a level under,[109] basically behind-the-scenes media infrastructures that in the simplest purposes support the storage, exhibition of an artifact and the comfort of a visitor. We also need to look at the 'old' media infrastructure that sits below the 'new', or where in some cases, the 'new' sits along side the 'old' and even further where the 'old' infrastructure has been remediated and refashioned and by that completely obliterating the presence of the past.[110]

METHODOLOGY FOR EXCAVATION 2.5.1

The study undergoes a detailed archaeology: the excavation, contextualization and diagramming of the museum to understand its infrastructure. Here, "archaeology means digging into the background reasons why a certain object, statement, discourse or, for instance in our case, media apparatus or use habit is able to be born and be picked up and sustain itself in a cultural situation."[111] Earlier we have discussed the problem contexts of infrastructure and energy footprints of the museum and how they are embedded in the 'deep time' of the museum. We follow this up with the case excavation of Cooper Hewitt Design Museum that allows us to chart the museum system, extract its components that form its infrastructure. As Fuller (talking about media environments) says — "the heterogeneity, the massive capacity for disconnectedness of the parts, coupled with the plain evidence of their being linked by some syntax, of writing or performative action, allows for the invention of newly transversal, imaginal, technico-aesthetic or communicative dynamics to flower"[112]....in other words, maybe enumerating the diverse components of a media system such as a museum could allow for new combinations of media infrastructure to materialize? Thus, our archaeology includes a rigorous listing of material and media components, their operative frameworks, relationships and energy analyses. A part of this archaeology involves diagramming (as shall be examined later) the museum system to understand the visible and invisible infrastructures that are related to energy consumption and energy embodiment. In the following, we examine the various methods used toward an archaeology of the museum infrastructure:

A. Contextualization:

We have looked at the background and problems of this dissertation in the earlier section. Based on literature and studies, the history and contemporary state of the field is presented and analyzed. This technological history works both backwards and forwards, a non-linear history that exposes the energy problems of media infrastructures and provides the context for a specific group of principles guiding this research and sets up the foundation for the design interventions.

B. Excavation:

Through 'excavation' we could assess the lifespans of various media infrastructures and determine when 'old' infrastructures 'leak' into new-media landscapes, when media of different epochs are layered palimpsestically, or when new infrastructures 'remediate' their predecessors.[113] Thus, we have conducted excavation on two levels. The first being the detailed excavation of the Cooper Hewitt museum system and secondly, an excavation that precedes each case projects. In the case of the museum, the excavation involved exposing the hidden components, processing and recording of the energy-intensive material and media structures that support the system. The Media Infrastructures have been grouped under 'Hard' and 'Soft'. The 'Hard' includes material infrastructure such as architecture, mechanical systems, storage, hardware etc. and the 'Soft' contains application programming interfaces, software, operational areas, protocols, algorithms etc. This is followed up by broad analytical units of components, their operative frameworks, relationships and energy data collection and analyses. In the case of the design projects, it involved digging into the respective problem contexts, processing through literature, interviews, surveys and observations, and recording the state of the field. In the excavation of the Cooper Hewitt, wherever we have encountered un-empirical information, we have attempted to present that data, as detailed as possible. In both the design interventions, we have provided detailed accounts for the readers to become part of the interpretive process and form their own opinions.

C. System Diagrams / Diagrammatics:

"Instead of the story, narrative, or image, Wolfgang Ernst's media archaeology posits the diagram as the starting point for an analysis of technical media culture: diagrams are to be understood in the very technical sense of a visualization of information patterns, circuits and relations which give an idea of how the otherwise so complex machines work.[114] The diagram shows how machines work, as a way of understanding visually the flow of signals in a structural way, but it also is a way to understand how society operates through the diagrams of machines." 'Engineering diagrams' provide a way to tap into the 'blueprints' of machines that offer us cultural content.[115]

According to Janell Watson, the theoretical principle of diagrammatic thinking or meta-modeling to filter out structures was also elaborated by Felix Guattari, as a useful method.[116] He sees the diagram as a site of production. Examples of the diagram at work include the algorithms of logic, algebra and topology; as well processes of recording, data storage, and computer processing; all of which are used in mathematics, science, technology and polyphonic music.[117] And, according to Mitchell, the usefulness of diagrams is also present in studies of literature and the other arts, and led to the establishment of an approach called diagrammatology.[118] In other words, "diagrams do not represent thought; rather, they generate thought." Guattari says that diagrams are abound in experimental science, because it is "a sphere where signs have a direct effect on things," involving "both material technology and a complex manipulation of sign machines."

Our diagramming during the research exposed a network of invisible components and layers of energy-intensive processes. Especially during the design interventions, we employed diagrammatic thinking with the various stakeholders and community participants.

METHODOLOGY FOR DESIGN INTERVENTIONS 2.5.2

The methodology behind the design interventions is practice-based. "Rather than a person working in a distant lab away from practice, the practitioner/researcher is studying his or her own practice as it develops and the question of methodology is thus shifted into new contexts of knowledge production."[119] Thus the research works directly with the media as a material that can be researched also through practical experimentation.[120] As such, the methodologies evolve and develop and often branch away to new ones. The complexity of the design interventions also forced us toward an approach of "methodological abundance"[121] The projects not only were about constructing research objects and tools in the public domain but also involved reflective practices in their design and implementation.[122] The study also pursued techniques and strategies utilized in Critical Making and Remediation studies.[123] These informed the emerging design framework that also shaped the trials, installations and infrastructure. Both quantitative and qualitative data was collected through case studies, questionnaires, workshops, fabrication sessions, collaborative work, trials and installations.

A. Constructive Design Research:

One of the key methods we started out with was Constructive Design Research. According to Koskinen et al., "we are dealing with research that imagines and builds new things and describes and explains these constructions."[124] The research intended to find solutions and new approaches through experimentation, research through design and deployment of projects. The experimental projects were engaged in studying by prototyping, building and deploying design projects that explored current museum practices in the real world contexts.[125] Building on such experimental art/science fields, the design interventions in this dissertation "demonstrate the possibility of a practice-led constructive media research that is not one of a completely controllable process, but as one of an active transformatory force capable of producing new forms of knowledge."[126] Thus, the methodology initially adopted for this dissertation was practice-based Constructive Design Research (CDR).This was circumscribed by "an important emphasis placed on the designers, the creative product and the critical process, and the approach to research involved moving from the 'known to the unknown' as new knowledge was constructed within the infrastructures opened up by the gaps in existing museum practices."[127] Our approach favored "a constant realignment of the construction of artifacts, based on trial and error, to better tackle the complexity of the design problems."[128] Our CDR method was enriched by Critical Making as discussed later on in this section.

B. Reflection-in-Action:

Donald Schön's 'Reflection-in-Action' was the underlying method used during the design intervention stage. We proceeded with these projects between 2012 - 2014 that challenged the existing practices and infrastructures of museums and heritage institutions with an underlying focus on digital strategies, participative systems and environmental concerns. These interventions were conceptualized, designed and implemented in collaborative teams, and involved 'reflection-in-action' wherein established museum theory and technique were set aside and new methods were constructed from each unique case.[129] Here, experimenting became a kind of action "where implementation was built into the inquiry and making, where means and ends were defined interactively as the projects progressed."[130] The projects followed a reflective strategy quite similar to the practice of architecture (of which the author has practiced between 2003-until present) where "each design move was a local experiment which contributed to the global experiment of reframing the problem."[131] Variability, "creating spaces of possibility in which the projects could move about was another preliminary accepted condition for the design to take place."[132] As such some research methods were delayed in application, some moves were resisted while others generated new and unpredicted results.[133] Thus the projects themselves became reflective design conversations within the research team, with the participants, institutions and the user communities.

C. Iterative:

The design interventions were to some extent iterative, i.e., aspects were repeated in an enhanced form (derivative) especially some of the hardware and methods.[134] The later intervention aimed to address the weaknesses and lost opportunities of the previous project. Lessons learnt from the first project were brought forward especially in the areas of hardware and fabrication. The process of community enrollment in the second project also benefitted from the first.

D. Critical Making:

The methodologies for the first design intervention 'Light is History' has its origins in 'Critical Making', a concept originated by Matt Ratto. It is "a mode of materially productive engagement that is intended to bridge the gap between creative physical and conceptual exploration: an intention to theoretically and pragmatically connect two modes of engagement with the world that are often held separate—critical thinking, typically understood as conceptually and linguistically based, and physical 'making, goal-based material work."[135] Ratto says that the creation of one's own tools permits critical analysis of the designs and constraints involved in the research, and thus avoids technologically-deterministic experimentation and directly confronts issues of pragmatism and theory. Critical Making according to Garnet Hertz is- "doing something yourself, as a non-expert, is a crash course in understanding how something actually works, and it is the fastest way to unpack and learn about the things that would normally remain invisible and taken for granted."[136] Although we embarked with the primary principles of Constructive Design Research, the methodology of Critical Making eventually took over as the principal method utilized in Light is History. The technique also extended to the second project where collaborators were engaged in Critical Making within a larger collaborative team.

E. Remediation:

Bolter and Grusin's Remediation theories have been utilized in the second design intervention at the Gallen-Kallela Museum.[137] It is a classic example of remediation albeit a reflective project implemented in a short span of time. Since the goal of the project was towards a short-term organized intervention towards a long term strategy of digitization for small museums, we consider this as a 'tactical' remediation approach. Digital media remediates its predecessors in many different ways as illustrated in our project. It is "a reading of old media and new media in parallel lines."[138] Our digitization system tried to refashion an old flat-bed scanner into an advanced portable deployment platform, without completely absorbing or hiding the old media away and therefore existed in a state of multiplicity, with the discontinuities between the old and the new were minimized. Our mutant system also remediated older forms of media into newer forms through its actions and processes whereby it remediated old ephemeral artifacts from the museum collections into digitized media placed in an online archive.

F. Circuit Bending:

We have used the methodology of 'Circuit Bending' in both the design interventions. Circuit bending is an electronic 'Do It Yourself' (DIY) movement undertaken by individuals without formal training or approval and focused on manipulating circuits and changing the taken-for-granted function of the technology. According to Hertz and Parikka, "the manipulator of consumer electronics often traverses through the hidden content inside of a technological system for the joy of entering its concealed under-layer, often breaking apart and reverse-engineering the device without formal expertise, manuals or defined endpoint."[139] They argue that "techniques of media-archaeological art like circuit bending are crucial for a wider environmental consciousness."[140] Our Circuit Bending in both interventions is preceded by the breaking of technological black boxes and rethinking them in a new light. In Light is History, we broke into a classic technological black box: the electricity meter and in the building of our digitization system we had to hack into the proprietary flat-bed scanner. We repurposed black-boxed media in both the projects, transforming them into novel open media artifacts with new operations and processes.

G. Other Operative Methods within Design Interventions:

These methods were discovered within the act of the design interventions themselves and were not pre-meditated. This can be considered as a result of reflective design practice within the research design. These methods arose during the inquiry and making and were defined interactively as the projects progressed.

These original methods discovered such as Microstructuring of the tasks and processes helped us to manage these complex projects. Open source software and hardware allowed us to inexpensively build our design, collaborate with communities and provide open access for our projects. Self-publishing of energy data in Light is History was crucial to the operations of the installation and the resulting public awareness and wellbeing. Our community-sourcing tactics at the Gallen-Kallela Museum resulted in gathering audience participation through active contribution of artifacts for digitization.

We were not alone in the design of the projects, but "always operated as part of a community, and as such this design 'activity' was affected by our participation within the communities."[141] In the process of the projects, "the design activity formed a loose system, that was partly embedded in an already existing system of societal and professional relationships."[142] This activity involved not only thinking and creating but also acting,[143] "where the projects themselves became processes that engaged the life and activities of the participating communities."[144]

We brought together Communities of Practice (for example, museum curators and collection managers) and Communities of Interest (local residents, programmers, hobby groups) onto the same stage.[145] This resulted in a transitional hybrid community. By the end of these experiments, some of these communities had continued onto other related projects and in some cases completely disbanded and disappeared. In this regard, it is quite similar to Diaz's 'Ephemeral Community' which is a transitory entity through which labor is organized, or how a community simply comes into being at different times for the purpose of engaging in an activity that has a projected result as a goal.[146]

H. Infrastructural Energy and Emergy Calculations:

We have made a detailed analysis of the infrastructural energy use and embodied energy or emergy. As discussed earlier in 2.3, a museum is a custodian of a collection of embodied energy, the operations and maintenance of which further requires energy, behind-the-scenes labor, maintenance, repair (operations are contingent on maintenance & users) knowledge. Therefore the footprint of a museum is not only its contents but also includes the energy needed to run this emergetic content. Thus, the calculation of embodied energy is a complex process that involves considering the energy used during the manufacture of devices, the contribution from components and materials of the device, and recursively the embodied energy of those components and materials.[147] Without understanding embodied energy, and only focusing on the energy use of infrastructures, we cannot come to an objective calculation of the carbon footprint of a device or an artifact.

For this, we had to analyze two facets of the museum's energy use. One was the museum's electricity use and the other was emergy —the energy required to build the media infrastructures that comprise the museum system. Conventional research typically ignores embodied energy, since it does not directly affect a museum's electricity consumption. Combining the two we attempt to provide a holistic estimate of museum energy use. We have used Circular Ecology's Embodied energy and carbon - ICE Database for a majority of our emergy calculations.[148] Other sources used in the calculations are listed in the Bibliography. We have also used the same methods of calculating energy and emergy for the design interventions.

2.5.3 CLARIFICATION OF ROLE AND POINT OF VIEW

The design interventions in this dissertation involve practice-based research in the sense that I've actively taken part in them as an architect, designer and researcher. It involves equally my own practice and also the practice of others. I see practice-based research as a collaborative process of investigation leading to new insights, that is then effectively shared. Going beyond the parameters of one's practice to provide a historical or conceptual context for a creative or professional practice is an important way of establishing whether new insights are being produced or not. I have stayed away from the reliance on the use of 'I' because it correlates with a drift away from research clarity and from providing any research context at all. This is usually because the researcher is conflating their own subjectivity, or individual experience, with the research project. At these moments, "the research topic becomes the researcher and not the research question."[149] Therefore, the case study and design interventions are described from the point of view of a team. The tables below describe the teams and roles of the two design interventions.

Table 2.2. Design Intervention 1: Light is History

	TEAM	FIELD	ROLES
1	KA	Design & Architecture	Design, construction and deployment of complete system.
2	Samir Bhowmik	New Media & Architecture	Design, construction and deployment of complete system.
3	MH	Wood Shop	Advice, assistance in construction.
4	MJ	Design	Programming

Table 2.3. Design Intervention 2: digGLAM at Gallen-Kallela Museum

	TEAM	FIELD	ROLES
1	Samir Bhowmik	New Media & Architecture	Coordination, design, research, planning,deployment
2	LD	New Media	Oversight, research, budgets
3	MH	Wood Shop	Advice, assistance in construction.
4	VK	Design	Industrial design
5	PM	New Media	Digital archive
6	PM (GKM)	Museum	Curatorial
7	AP	Computer Science	Programming
8	JR	Computer Science	Oversight, research
9	SR (GKM)	Museum	Event Planning
10	MT (GKM)	Museum	Collections
11	TW (GKM)	Museum	Oversight, research
12	AV	Art	Communications, planning, documentation

SUMMARY 2.6

The contextualization of museums with regards to media infrastructure uncovered its media history and traced the transition of the museum to the current media context. We explored briefly the origins of the museum and traced the rise of the mediatic museum through literature and examples. Instead of a linear history of the development of the museum, we examined episodes, missed opportunities and turning points. We then explored energy use and embodied energy through the entanglements with the museum's media infrastructure. Technological black boxes and the effect of black boxing on the museum were also briefly examined. We critically analyzed sustainability, both at the broader environmental level and at the scope of media and the museum. By examining the entanglements between media infrastructures of the museum and energy, the scope and thesis of this dissertation was defined. The methodology as elaborated is multi-disciplinary and practice-based. The dissertation necessitated a wide assortment of methods such as the media archaeological excavation and contextualization to study the museum infrastructure, and design methods such as critical making to critical remediation that were utilized in the design interventions. Finally, roles have been clarified and a brief description of the point of view of the research was established. Proceeding from this historical and methodological foundation, the dissertation can now excavate the contemporary museum and the materiality of its media infrastructures.

NOTES TO CHAPTER TWO

1 Zielinski, *Deep Time Of The Media: Toward An Archaeology Of Hearing And Seeing By Technical Means*, 31.

2 Zielinski, Deep Time Of The Media, 1-11. Zielinski suggests that we should not only look back in time to discover the new in the old, but also examine marginal contemporary media practices to encourage an alternate development of future media. He says that the goal is to uncover dynamic moments in the media-archeological record that abound and revel in heterogeneity… to enter into a relationship of tension with various present-day moments, relativize them, and render them more decisive.

3 Ibid., 1-11; Jussi Parikka, *What Is Media Archaeology* (John Wiley & Sons, 2013); Erkki Huhtamo and Jussi Parikka, "Introduction: An Archaeology Of Media Archaeology, " in *Media Archaeology: Approaches, Applications, And Implications*, ed. Erkki Huhtamo and Jussi Parikka (Berkeley And Los Angeles: University Of California Press, 2011), 1-21.

4 Tom Eggington, "Athanasius Kircher, Musurgia Universalis, 1650" in Special Collections featured item for November 2004, https://www.reading.ac.uk/web/FILES/special-collections/featurekircher.pdf (accessed March 7, 2016).

5 Zielinski, *Deep Time of Media*, 5. According to Zielinski, the concept of 'deep time' can be traced back to John McPhee's Basin and Range (1980).

6 Shannon Mattern, "Deep Time of Media Infrastructure," in *Signal Traffic: Critical Studies of Media Infrastructures*, ed. Lisa Parks and Nicole Starosielski (Urbana, Chicago And Springfield: University Of Illinois Press, 2015), 95-102.

7 Ibid., 98; Shannon Mattern, "Ear to the Wire: Listening To Historic Urban Infrastructures," Amodern 2 (Fall 2013), http://amodern.net/article/ear-to-the-wire/ (accessed January 12, 2016).

8 Mattern, "Deep Time of Media Infrastructure," 102. Mattern proposes that the study of media infrastructure should take inspiration from the field of Media Archaeology, especially from the work of Siegfried Zielinski, and from the field of geology, infrastructural studies, architectural and urban history.

9 Lewis Mumford, *The Culture Of Cities* (New York: Harcourt, Brace, Jovanovich, 1966), 6; Mattern, "Deep Time of Media Infrastructure," 95. Mattern says that the "area of local intercourse" is an infrastructure—a structure that undergirds communication and communion.

10 Raymond Williams, *Marxism And Literature*. Vol. 1 (Oxford University Press, 1977), 122.

11 Bolter and Grusin, *Remediation: Understanding New Media*, 44-50.

12 Mattern, "Deep Time of Media Infrastructure," 97.

13 Lily Diaz-Kommonen, "Can The Muses Be Revived?" (in Future Fusion, Applications Realities For The Virtual Age, Proceedings Of The 4th International Conference On Virtual Systems And Multimedia, Gifu, Japan, Volume Two, IOS Press, 1998), 439, http://mlab.uiah.fi/systems_of_representation/muses.pdf (accessed February 9, 2016).

14 Ellen Brundige, "The Library Of Alexandria," in *The Perseus Project* (1998), http://perseus.mpiwg-berlin.mpg.de/greekscience/students/ellen/museum.html (accessed February 9, 2016). Brundige says that the Museum of Alexandria was founded at a unique place and time which allowed its scholars to draw on the deductive techniques of Aristotle and Greek thought, in order to apply these methods to the knowledges of Greece, Egypt, Macedonia, Babylonia, and beyond. The location of Alexandria as a center of trade, and in particular as the major exporter of writing material, offered vast opportunities for the amassing of information from different cultures and schools of thought.

15 Andrew Erskine, *Culture And Power In Ptolemaic Egypt: The Museum And Library Of Alexandria* (Greece And Rome, Second Series, 42, No. 01, 1995): 38-48, http://www.jstor.org/stable/643071 (accessed February 10, 2016).

16 Paula Young Lee, "The Musaeum Of Alexandria and The Formation Of The Muséum In Eighteenth-Century France." *The Art Bulletin*, 79-3 (1997): 385, doi: 10.1080/00043079.1997.10786791 (accessed February 9, 2016).

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organizing vista of thematic canvases. On the walls are 34 paintings representing mythologic or religious subjects and representing various trades. The arrangement was such that paintings were somehow related to their neighbors, and emblematic of the objects in the cabinets below.

18 Zielinski, *Deep Time Of The Media: Toward An Archaeology Of Hearing And Seeing By Technical Means*, 67.

19 Peter Davis, *Ecomuseums: A Sense of Place* (London: A&C Black, 2011), 6-8.

20 Paula Findlen, *Possessing Nature: Museums, Collecting, And Scientific Culture In Early Modern Italy* (University Of California Press, 1994).

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22 Such as Kircher's Panacousticon, a design for a surveillance system of courtyards and public spaces where every word can be overheard. The talking heads were developed as are part of the gallery entrance to the museum and they would speak whenever someone passed by.

23 Zielinski, *Deep Time Of The Media: Toward An Archaeology Of Hearing And Seeing By Technical Means*, 125.

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25 Tony Bennett, *The Birth of the Museum: History, Theory, Politics, Culture* (London: Routledge, 1995), 25-32.

26 Davis, *Ecomuseums: A Sense of Place*, 7.

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28 David Elliston Allen, *The Naturalist In Britain: A Social History* (Princeton, NJ: Princeton University Press, 1976).

29 Diaz-Kommonen, "Can The Muses Be Revived?" 439; Lee, "The Musaeum Of Alexandria and The Formation Of The Muséum In Eighteenth-Century France," 385.

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31 Davis, *Ecomuseums: A Sense of Place*, 8.

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35 Henning, *Museums, Media and Cultural Theory*, 74. Henning presents a materialist viewpoint to the history of the media-intensive museum.

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EXCAVATION

3.1 INTRODUCTION

Under the shiny multi-touch tables,[1] retrofitted museum building and open cloud collections of the Cooper Hewitt Smithsonian Design Museum lies extensive energy-consuming material and media infrastructures.[2] Most of these are invisible to the Cooper Hewitt's audience and in some cases even beyond reach for the museum's own staff and personnel. As media technology has progressed in technological sophistication (including and not limited to management of digital assets and climate control systems of the museum) and applied in the museum, it has propagated blackboxes within the museum system. This has often resulted in the need for expanding pockets of specialized personnel and equipment. Not only the hidden infrastructures are material-intensive with high Emergy but also depend on considerable amounts of electrical power for operations. Despite the Cooper Hewitt aiming to be an 'open' museum, its material and energy footprint tells us a story of perpetual energy and infrastructural dependence.

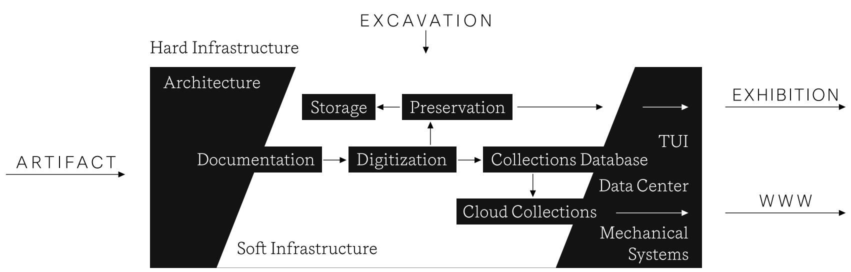


Fig. 3.1. Excavation of the museum blackbox.

Our study involved a detailed excavation, applying Bowker's 'infrastructural inversion'-foregrounding the truly backstage elements of the Cooper Hewitt museum system.[3] An evolving technological medium, a soon-to-be 'punctualized' object, the Cooper Hewitt museum 'blackbox' is quite similar to any other technological gadget, where the inputs and outputs are currently the only publicly known features as mapped in Figure 3.1. Within the main blackbox lies other smaller blackboxes, and within those are still others. Most of the blackboxed infrastructure of the museum is working behind the scenes to support design artifacts and provide augmented visitor experiences both in the physical space as well as online. And, since the museum's goal is not only to expand its web presence but also synchronize digital assets with physical visitation, it calls for a relentless retro-fitment and up-grading of blackboxed material and media infrastructures.

The single biggest materiality of the Cooper Hewitt is its historic museum building that forms the underlying infrastructure, as will be discussed in 3.4. The Carnegie Mansion was not designed to be a museum, but was adapted for reuse by the Smithsonian Institution. This incurred a substantial retrofitting of the fragmented internal spaces to modify them for public exhibition. Behind the walls and under the ceilings run large-scale HVAC systems that are configured to support preservation-level climatic control and visitor comfort. Cabling for media exhibits, lighting systems, fire-safety sensors and electrical points, all are embedded within the substructure of the museum. Sprinkler systems, water supply and sewage systems form another complex hidden material layer inside the walls of the museum. The energy the museum complex consumed in 2014 was on average 650 mmbtu and its carbon Footprint exceeded 1316 cars/ year or 6.25 Metric Tons.[4]

The conservation and storage facility of the Cooper Hewitt in New Jersey is another concealed material infrastructure. The facility is located in a remote low-cost storage warehouse off-limits to the museum audience. It is equipped with energy-intensive climate control to provide the desired stable interior climate for optimal conservation of objects,[5] leading to large economic and ecological costs. The artifacts stored here constitute a high proportion of the Cooper Hewitt design collections. The HVAC infrastructure constructed per object and the resulting energy consumption is large percentage of the museum building itself.

The media infrastructure within the retrofitted museum building is composed of another array of energy-intensive blackboxed technologies. Starting from the multitouch tables, wall projections, vertical touchscreens, registration stations, in-house wifi access, all of these is are supported by proprietary hardware and software. The technology especially under the multitouch is patented and blackboxed and not openly available. The digital collections that link to the media exhibits are linked from the Cooper Hewitt's cloud collections and ultimately the Smithsonian Data Center in Virginia. The cloud collections are placed in Amazon Web Service's cloud hosting services that offers a package of instances (virtual servers) that store and deliver the museum's digital content upon demand. Amazon's cloud services and data centers have been criticized for their operational secretiveness and blackboxed energy-intensive infrastructure. Finally, the Smithsonian's own data center forms the base media infrastructure of the Cooper Hewitt where the permanent digital collections are stored.

The Cooper Hewitt has adopted several innovative methods (3.6.) to augment the museum experience, i.e. embarked upon major themes that drive the relations between its material and media infrastructures. Chiefly among them is the application programming interface (API) that provides a gateway to its 'open' collections and the negotiation of collections in the museum through tangible user interfaces (TUI). These along with the retrofitted building form the current digital strategy of Cooper Hewitt. But, despite the innovative technologies and methods adopted by Cooper Hewitt, an infrastructural energy analysis in 3.7 shows a considerable energy footprint of all systems. To arrive at this conclusion, we had to analyze two facets of the museum's energy use. One is the museum's electricity use and the other is embodied energy (emergy)—the energy required to build the blackboxed devices and infrastructure that comprise the Cooper Hewitt system. Conventional research typically ignores emergy, since it does not directly affect a museum's electricity consumption. By combining the two we attempted to provide a holistic estimate of the museum's energy use.

The analyses show an energy-consuming museum that depends on material and media infrastructures to support collections and museum visitation. Are these invisible material-intensive infrastructures responsible for increased energy consumption? Could visibility and unpacking of the various blackboxes within the museum increase 'openness' and reduce energy consumption in the long term? The following sections present an excavation and mapping of the Cooper Hewitt museum's system, methodologies and energy footprints to understand the manifold aspects of its underlying energy-using infrastructure.

CASE METHODOLOGY 3.2

We examined two sets of materialities embedded in the Cooper Hewitt museum infrastructure, one that was expressed in the architecture, the tangible devices (hard) and the other that existed in the computing languages (soft), that negotiated the museum's digital content. Thus, the museum was analyzed step by step, being devised into broad analytical categories such as hard, soft media infrastructures, and resulting from that analyses operative methodologies and infrastructural energy data. These units were further developed and refined to categories and subcategories. The goal was to filter out a particular archaeological structure from the museum that included both the visible and the invisible, the hard and the soft.

The following methods were used to analyze the museum infrastructure:
A. Energy Data Recording: Energy-use data of the museum's "Cloud" Collections, Digitization and Museum Building was collected. The goal was to assist the Museum to build a Sustainability Roadmap for the institution to save energy, cut operational costs and reduce carbon footprints. The Cooper Hewitt already has a Sustainability Plan in the works shaped by the Smithsonian's Energy Saving Plan and Energy Management Team. However the plan was yet to be fully implemented as of April 2015.

The data acquired between May 2014 and March 2015 was mapped. It includes Energy readings from 2014 of the Museum complex

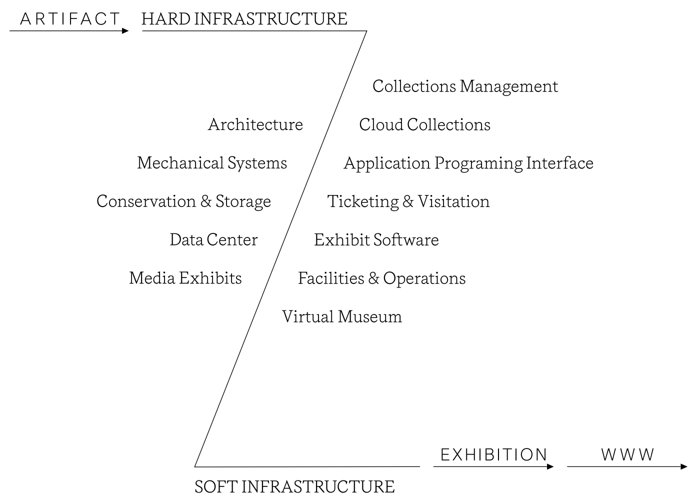


Fig. 3.2. Diagram of Hard and Soft Media Infrastructure.

in Manhattan, New York and Smithsonian Herndon Data Center in Virginia. Energy usage of Preservation and Digitization processes at the Cooper Hewitt Newark Storage Facility in New Jersey has also been taken into account. Extra data was received in early 2016 that includes the time during which the renovated museum was operational.

B. Interviews: The study interviewed the personnel of the Museum, such as the Director of Emerging Media, Information Technology Officer, Registrars, Curators, Head of Exhibitions and Operations & Facilities Management. Their views and insights have been weaved through this study. Also email correspondence has been used where interviews could not be undertaken.

C. Metrics: Online usage through Amazon Web Service (AWS) and Google Analytics has been analyzed.[6] The museum provided access to both during the author's research visit. It has been used to compare with energy use and actual visitation numbers at the museum.

D. Reports: The Smithsonian Information Technology Plan was used as reference.[7] It should be noted that new data and savings policies are being generated everyday by the Cooper Hewitt, and the findings in this paper merely refer to a brief glimpse of energy consumption. The other reports used was the Smithsonian Digitization Strategic Plan 2010.[8]

E. Blog: The Cooper Hewitt Labs blog,[9] that publishes internal research of the digital labs at Cooper Hewitt was extensively utilized to gather details of various systems and software. Here one can find the latest publications, results and digital experiments conducted at the museum.

CONTEXT 3.3

THE CARNEGIE MANSION 3.3.1

The Cooper Hewitt Smithsonian Design Museum is housed in the Carnegie Mansion high up on the Museum Mile in Manhattan, New York.[10] The mansion was donated to the Smithsonian by the Carnegie Corporation, the charitable organization established by the steel magnate Andrew Carnegie, — "to house a collection of objects that has never quite seemed at home amidst the opulence and grandeur of the neo-Georgian stone and brick pile on Fifth Avenue. The mansion is locked in a particular past, full of wood paneling, stained glass, carved ceilings and even a themed room full of ornately detailed Indian teakwood."[11] The mansion was designed in the Georgian style by the architectural firm of Babb, Cook & Willard, and completed in 1901. The property includes a large private garden, a rarity in Manhattan. The house includes many innovative features. It was the first private residence in the United States to have a structural steel frame and one of the first in New York to have a residential Otis passenger elevator. The house also had central heating and a precursor to air-conditioning.[12]

Fig. 3.3. The Cooper Hewitt Smithsonian Design Museum. All copyrights belong to CHSDM.

From the 1940's to the 60's the house was used as the Columbia University School of Social Work. In the late seventies the brick and limestone building was transformed into the Cooper Hewitt museum, renovated to house the decorative arts collections originally assembled for the Cooper Union by the Cooper and Hewitt families.[13] Initial remodeling was done in 1976 to adapt the mansion to a museum. However, according to Sebastian Chan, the mansion created a certain type of "threshold fear" that Cooper Hewitt needed to overcome through a combination of architectural and social interventions and unlike the "threshold fear" invoked by the grand architectures of the 19th (and early 20th) century public buildings, Carnegie's residence with its high fence was purpose-built to keep people out.[14] The Smithsonian, through an internal review of the Cooper Hewitt's long-term viability found that visitation was low and thus a renovation was announced "to counter its reputation as a sleepy institution hampered by its setting in the ornate turn-of-the-century Carnegie Mansion."[15] The goal of the renovation was to expand exhibition spaces, integrate emerging digital media and eventually to enhance and promote visitation. According to Jocelyn Groom, the Head of Exhibitions, the renovation was also meant to create back of house efficiencies related to exhibition production and installation, and upgrade critical systems such as electrical and lighting.

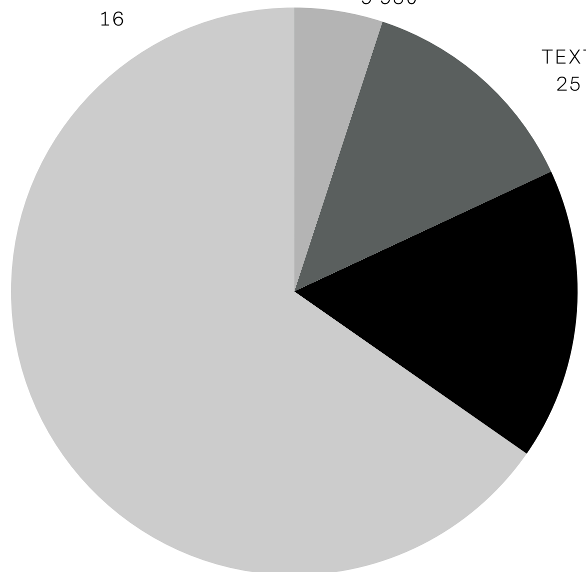


Fig. 3.4. Chart of the Cooper Hewitt collections[20]

The Cooper Hewitt thus experienced both digital and material infrastructural change from 2007 onwards until 2014 when it reopened. 16000 square feet of exhibition space was renovated, new HVAC systems integrated, in addition to new gallery areas at the cost of 91 million USD. The Mansion has been awarded a USGBC's LEED Silver certification, a rating based on set of criteria for ecologically friendly construction.[16]

THE COOPER HEWITT CURATORIAL DEPARTMENTS AND COLLECTIONS 3.3.2

The Collections consist of decorative arts originally assembled for the Cooper Union by the Cooper and Hewitt families.[17] There are 84 countries represented in the online collection spanning 78,373 objects from 102 periods.[18] The Museum has 6 curatorial departments and a conservation department.[19]

A. Archives holds 16 objects

B. Drawings, Prints, and Graphic Design houses works on paper in the fields of architecture, decorative arts, gardens, interiors, jewelry, theater, industrial and graphic design, and fine arts. There are 129,175 objects from this department.

C. Product Design and Decorative Arts encompasses a broad range of decorative arts, industrial and contemporary designs objects including ceramics, furniture, metalwork, lighting, glass, jewelry, architectural elements and industrial design. There are 32,890 objects from this department.

D. Textiles department represents woven and non-woven techniques and a wide variety of printing and dyeing methods. There are 25,754 objects from this department.

E. Wallcoverings department contains the largest collection of wallpaper in the United States from hand-printed, bespoke designs to mass-produced décor. There are 9,950 objects from this department.

F. Digital: There are 4 objects from this department.

G. Conservation: The Conservation department supports the Curatorial Division as well as the Exhibitions and Registrar Departments to preserve the museum's collection and loaned objects while on exhibition and in storage. The Conservators analyze and treat the objects to maximize their longevity, aesthetic quality, and technical interpretation.

3.3.3 MEDIA COMPONENTS OF THE MUSEUM

The Museum has 2 physical locations and 2 virtual. All it's major components, together forming the physical and digital infrastructure of the Museum are listed here. Figure 3.5 shows the progression of the

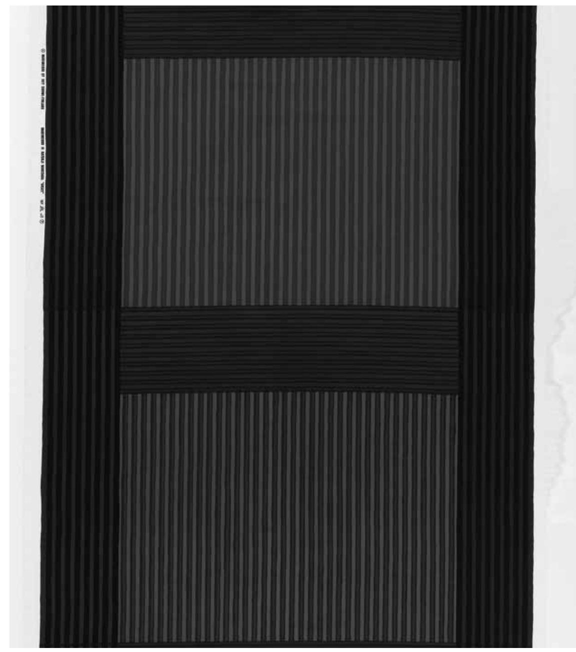


Fig. 3.5. *Top left*, Compact Disk Cover for David Byrne's "Feelings", 1997; *top right*, Cat and kitten Figure, late 19th–early 20th century; probably Austria; *bottom left*, Chair (England), ca. 1844; *bottom right*, Printed Textile, Ukset, 1977.

design object acquired by the Museum from digitization and storage to display at an exhibition and long-term safe storage at the Smithsonian Data Center and Amazon Web Services.

A. Museum (Exhibition): The Main Museum building is in Manhattan, New York City, earlier the Carnegie Mansion. Attached to the Mansion are the Townhouses where the offices, labs and library are situated.

B. Newark Off-site Storage & Digitization Facility (Digitization & Storage): The Off-site Collections and Digitization facilities are housed in a Storage Facility “3 West” in Newark, New Jersey.

C. Smithsonian Herndon Data Center (Permanent Digital Collections): The Cooper Hewitt’s main digital collections reside in the Smithsonian Data Center in Herndon, Virginia.

D. Amazon Web Service (Cloud Collections): The Museum’s public website and publishing is run through Amazon Web Service (AWS).

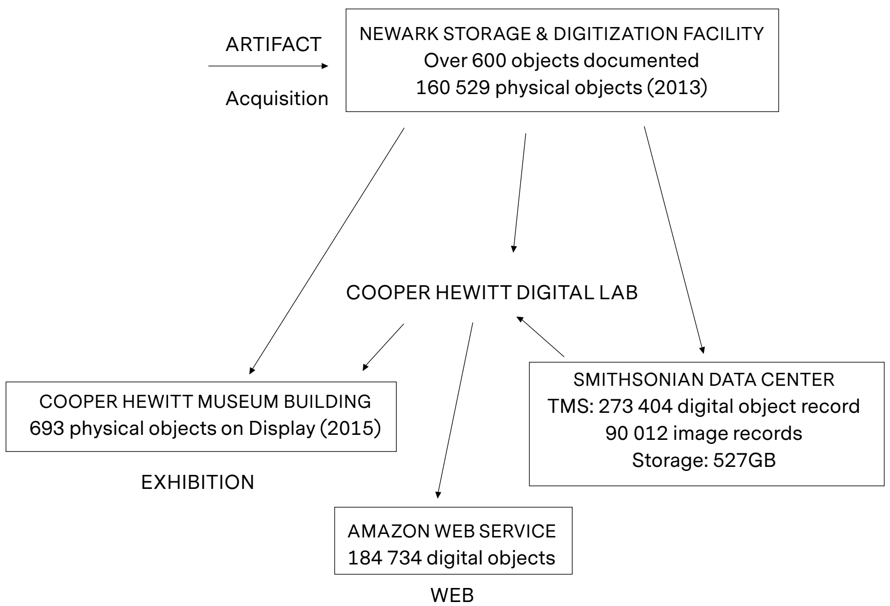


Fig. 3.6. The media infrastructure of the museum.

HARD MEDIA INFRASTRUCTURE 3.4

ARCHITECTURE 3.4.1

Carnegie Mansion was meant to be a private residence and not a public museum. Its owner commissioned a mansion concealed from the public view yet with its own garden and proximity to Central Park. “Within, the Carnegies were obsessed with technology. Theirs was the first private home in the United States to have a structural steel frame, was one of the first to boast a passenger elevator, and was extremely progressive in its use of central heating and air conditioning. The Carnegie mansion even included duplicates of every major piece of equipment, in case of failure. Although its systems were hidden in the walls, the house was, in every sense, a showcase for turn-of-the-century technology.”[21]

The museum building again underwent renovation between 2010 until 2014 during which 6000 square feet of exhibition space was added to total 17000 square feet. In the renovation, new mechanical and electrical systems were installed, fire egress stairs built, accessible routes, fire detection and sprinklers were integrated. A Historic Structures Report and a Preservation Plan were generated to inform remodeling work. The gallery spaces were restored assisted by a materials conservation studies. The original spaces were documented and representative finishes and details saved as part of the historic record. The renovation also included cleaning and repair of exterior masonry and the historic wrought-iron fence.[22] The first-floor galleries of the mansion were restored to provide improved spaces to incorporate new media technologies. Second-floor galleries were expanded by converting existing office space for the museum’s permanent collections and temporary exhibitions. Administrative offices were moved to the adjacent Miller & Fox Townhouses. Additionally, a new 6,000-square-foot gallery was added on the third floor for public exhibitions.[23]

The museum building is the primary public component and tangible material infrastructure of the Cooper Hewitt museum system. It is

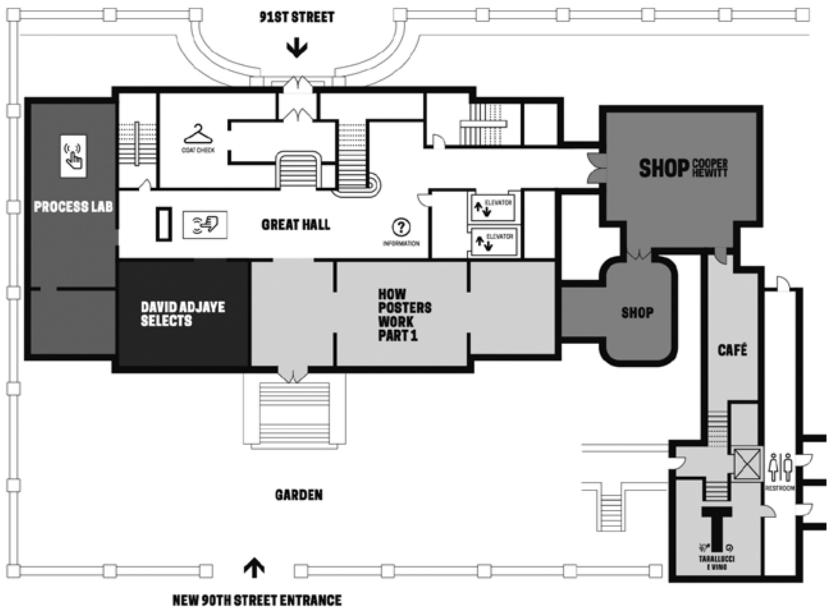


Fig. 3.7. First Floor Plan of the Cooper Hewitt. Image courtesy of Cooper Hewitt Smithsonian Design Museum.

structured in four stories including an attic and three basement levels. The spaces themselves do not provide the flexibility needed for a design museum with its rigid arrangement of walls. Nor is it a dynamic communication machine like other column-free and modern museums. The volumes are fragmented, spaces do not have depth of perspective and some are unsuitable for presentation of design heritage. Since its a historic landmark, the building entails a constant monitoring of its internal structures and external surfaces and as such is also a hostage to its own history.

MECHANICAL SYSTEMS OF THE MUSEUM 3.4.2

Behind the public facade of the galleries and exhibition halls of the Cooper Hewitt, complex heating, ventilation and air conditioning (HVAC) systems are used to optimize the indoor climate for preservation and visitors' comfort. Controlling the Relative Humidity (RH) as tightly as possible is considered the best possible course. Guidelines with a strict allowable bandwidth for RH are based on the mechanical limitations of HVAC systems rather than on museum's collection needs. Optimizing the indoor climate of the museum primarily by mechanical systems is favored over design and architectural features. These tight boundaries for temperature and RH often resulted in the assembly of vast and energy-guzzling equipment.[24]

During the renovation, new HVAC systems were integrated, in addition to new gallery areas, adjusted for the incorporation of new media exhibits. This forms part of the primary infrastructure that services both the Mansion and the administration building (Miller & Fox Townhouses), followed closely by the lighting systems, security, cabling, indoor transportation systems and wireless network systems. The HVAC itself consists of a series of interlinked material apparatuses such as dampers, pre-filters, preheating coils, supply fans, cooling coils, reheating coils, humidifiers, return fans, air handling units and room sensors. All these together serve to provide suitable indoor air quality for preventive conservation of artifacts and thermal comfort for visitors in the exhibition areas.

The lighting systems are based on sensors and timers, linked to the security cameras and other alarm devices. Cables, ducts and wires housed in metal trays are secured and hidden from view in an interstitial floor above the foyer level. The ceilings of all the galleries (every floor) were disassembled so that electrical, plumbing, security, and other infrastructure could be installed. Vents, pipes, meters, monitors, switches, valves form another complex infrastructure of plumbing and sanitation within the museum building.

The materiality and embedded energy of this infrastructure is hard to comprehend and calculate. But for an old heritage building such as

Fig. 3.8. *Top*, The Cooper Hewitt under renovation. Photograph by Uncommon Fritillary, distributed under a CC BY-NC-SA 2.0 license; *bottom*, interior renovation under progress at the Cooper Hewitt. Photograph courtesy of Cooper Hewitt Smithsonian Design Museum.

the Carnegie Mansion, it is inevitable to utilize mechanical systems rather than change historical architectural features. This invisible infrastructure of mechanical climate control is an essential support system for the design artifacts on display at the museum.

CONSERVATION & STORAGE 3.4.3

The infrastructure needed for the storage of museum collections is another concealed component of a museum system. In most cases, these spaces are located off the premises, or in basements and low-cost storage facilities beyond the eyes of the museum audience. These storage spaces are often equipped with extensive interior climate control to provide the desired stable interior climate for optimal conservation of objects leading to large economic and ecological costs.[25] The artifacts here usually constitute a high percentage of a museum's collections since at any given time exhibition facilities can only support a fraction of the total artifacts.

Fig. 3.9. The Crozier Fine Arts Building in Newark, New Jersey is home to the Conservation and Storage department of the Cooper Hewitt. Screenshot from Google Maps Streetview.

The Cooper Hewitt's conservation and storage facility 3 West in Newark, New Jersey functions as a physical repository for the museum's artifacts collections. This is another invisible infrastructure in the Cooper Hewitt museum system. The building itself is a converted warehouse in a bleak neighborhood of Newark owned by Crozier Fine Arts, an arts warehousing company. It is located on Johnson Avenue next to the international airport and the Interstate 78 that provides a straight connection to Manhattan via Holland Tunnel. This large white concrete building has a 100 meter by 100 meter square floor plan with 6 windowless sealed floors surrounded by high fences and surveillance cameras. All street level windows and entrances are blocked off save for the main entrance that has a double security door.

In the high-ceilinged storage areas of the Cooper Hewitt on the second floor, thousands of design artifacts are placed in separate climate controlled chambers. Each room is filled with mobile compact storage units as well as tall metal storage racks placed in rows along passageways. Artifacts are either wrapped in packaging or crated in these racks. Early Herman Miller chairs dot the collection without occupants, and a plethora of design artifacts lie around wrapped in cellophane. Each individual storage rack is identified by its number and code sticker and placement on a floor plan layout. In the ceiling, there is a vast network of air ventilation ducts, pipes, cables, cameras and exposed sprinkler-heads. The lighting fixtures are bright fluorescent. 96 security devices are deployed within these chambers. In a smaller chamber inside multiple sealed glass compartments are older design artifacts from the early 20th century. More than 200 000 objects are stored in these storage chambers overseen by 6 curatorial departments, of which only a small portion goes on to be staged at the exhibition galleries of the Carnegie Mansion in Manhattan.

In 2014, Cooper Hewitt did not have a substantial digitization lab. Besides a photo-documentation studio there were no automated mass digitization facility. The Cooper Hewitt's collections are in majority composed of three dimensional design objects except for the wallpaper collections. 3D digitization has not been initiated yet with the Cooper Hewitt's collections and the collections online show only 2D

Fig. 3.10. Two interior views of 3 West, the storage areas of the Cooper Hewitt collections. Photograph courtesy of Cooper Hewitt Smithsonian Design Museum.

images. Cooper Hewitt's parental body, the Smithsonian however has extensive digitization facilities. In its Digitization Plan 2010, it has outlined that all individual digitization activity of various Smithsonian museums will be moved and integrated under a single Smithsonian Digitization Program.[26] This also includes a common digitization portal for the exchange of knowledge and informations and the sharing of tools and means for digitization across all Smithsonian institutions.

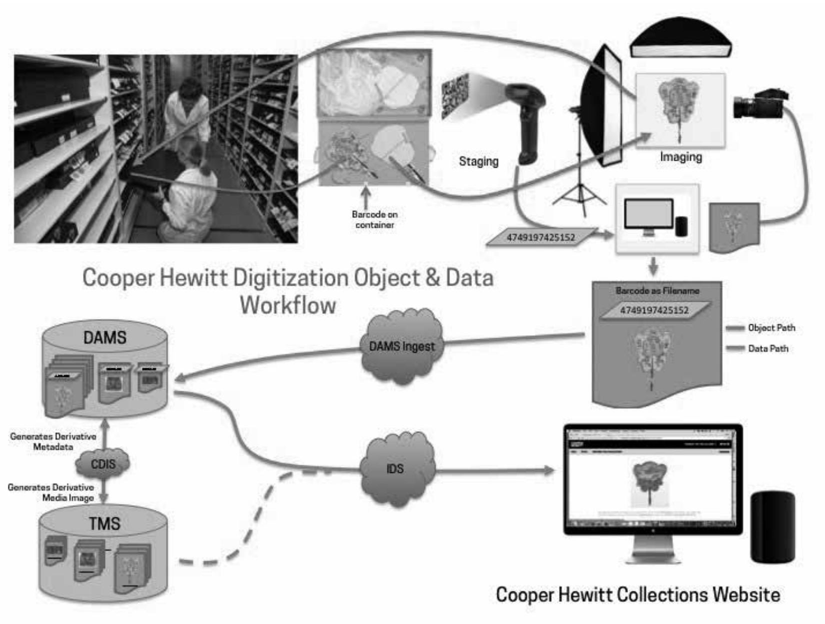


Fig. 3.11. The Digitization workflow at Cooper Hewitt. Sketch by Allison Hale, Courtesy of CHSDM.[27]

The digitization or the photography room within 3 West is modest in scale and scope. This is where the Cooper Hewitt design object begins its digital journey, if not earlier through curator's record shots during acquisition. Two medium-format cameras,[28] a couple of strobe lights, battery-powered flash generators and a desktop computer inside a large double-height studio space form the complete infrastructure of the Cooper Hewitt's digitization program. There are also the local storage, such as the four RAID (Redundant Array of Independent Disks) Hard Drives that store the digital images until they are transmitted to the Smithsonian Data Center in Herndon. The staff in Newark access these images on personal laptops. In 2013 alone, 6604 objects were documented and 9695 record shots were taken.

The storage areas, registrar workspace, collections study, photography, and conservation lab space constitute the entire second floor area of the Crozier building. They are the back office of the Cooper Hewitt where critical conservation operations take place away from the public eyes. A large building energy use footprint including the energy costs of transportation of artifacts back and forth has been the prime outcomes of this isolated and invisible infrastructure.

CLOUD COLLECTIONS 3.4.4

Today, a museum's online digital collections are situated, negotiated and sustained by data centers and cloud computing services. This is due to emerging museum practices that are allowing a larger amount of digital collections to be viewed on the Internet beyond the physical limitations of exhibition and storage. The proliferation of online museum audiences and social networks has also amplified the dissemination of digital cultural content. Cloud computing allows museums to avoid large investments in computer server infrastructure, gets their web applications up and running faster, with improved remote manageability and with less maintenance. This however has led to dependence on Cloud computing services that provide on-demand access and remote hosting of digital collections. These services and infrastructures although low-cost, are not only inefficiently organized, but are also energy-intensive and employ proprietary technology and standards to provide merely unidirectional flow of information.[29]

In fact, the Cloud in its physical manifestation is a large concrete-steel warehouse: a Data Center housing thousands of dedicated computer servers under strict air conditioning, multiple energy backups and redundancies. Data Centers are invisible infrastructural and

Fig. 3.12. *Top*, HVAC infrastructure at the Smithsonian Herndon Center. Photograph by Martin Kalfatovic, distributed under a CC BY-NC-SA 2.0 license; *bottom*, server racks inside the Smithsonian Herndon Center. Photograph by Martin Kalfatovic, distributed under a CC BY-NC-SA 2.0 license.

technological black boxes. They contain entire arrays of computer systems, storage components, air conditioning, fire suppression devices, security controls and redundant telecommunications connections. Cabling trays, standard racks to mount equipment, raised floor systems, and many other material components form the infrastructure of a Data Center. Not only these have high emergy, in their entirety are energy-consuming: require huge amounts of dedicated electrical power, but also the design of the spaces and internal operations are concealed from the public.

The Smithsonian Data Center is the perfect example. It is a nondescript brick building in the outer suburbs of Herndon, Virginia. It houses the significant digital collections (the Smithsonian has over 137.7 million objects and specimens) of the Institution's nineteen museums and galleries.[30] (Smithsonian 2015) including the Cooper Hewitt's digital collections. The Data Center houses over 1000 servers maintained by 100 personnel. It contains the brain of the Smithsonian. It comprises digital heritage collections, scientific, and administrative data. Its operation and maintenance is vital to the functions of the Smithsonian Museums, research centers and public access to information. Its Energy Reading in May 2014 was 1723 kWh (Average of 20 676 kWh annually). Equivalent to 1.2 Metric Tons of Carbon Dioxide Emissions. 134 Gallons of oil consumed, 1276 pounds of coal burned. Its UPS meter reading was 278 KW. About 0.192 Metric Tons. Together they clock carbon emissions of over 16.5 tons of CO2 annually. 13.6 acres of forests could only offset that. The calculations are based on U.S. Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator.[31] See Appendix.

Within the Data Center, two computer servers handle the collections database of the Cooper Hewitt's TMS (The Museum System 2015) archival database.[32] The servers contain over 273 404 object records and 90 012 image records. 527 GB of disk space out of allocated 729 GB, and still growing. The Collections database is the backbone of Cooper Hewitt's daily museological operations. The servers assigned to Cooper Hewitt consume over 20 kWh/per month. A calculation shows that the carbon emissions is equivalent to 178 pounds of coal burned, the footprint of Cooper Hewitt's design heritage.[33] The Smithsonian Data Center's energy sources are mostly non-renewable. The need for online access to the Cooper Hewitt's audience depends on this hidden infrastructure in Virginia with its thousand servers holding millions of digital artifacts.

3.4.5 MEDIA EXHIBITS

New Media technologies in the form of tangible media exhibits form another separate family of infrastructure within the museum. These are screens, monitors, projectors and similar hardware linked or in isolation to the artifacts displayed in a museum's exhibition gallery. They usually provide additional visual information about the artifacts or immersive interactive experiences including games designed to interact with the digital representations of the artifacts. These exhibits are either standalone displays with a computer program running in the background or networked to the online collections of the museum and in some cases linked to a hand-held device. The hardware of media exhibits is basically composed of central processing units, a display screen that is either touch-screen or controlled by a mouse and keypad. In some advanced exhibits, tangible user interfaces and or virtual reality headsets are also part of the hardware.

Fig. 3.13. A multi-touch table at the Cooper Hewitt. Photograph by Kevin Jarrett, distributed under a CC BY-NC-SA 2.0 license.

In an attempt to virtually animate design artifacts, Cooper Hewitt has focused on emerging media technology-mediated experience of the museum's collection to present an interactive experience and not just artifacts in glass cases. Prior to the renovation when the exhibitions were still active, roughly 25% to 33% were screen or projector based. For some larger exhibitions, that proportion was as high as half. With the new redesign of the exhibition spaces, the museum has much larger screens and projections in virtually every room of the galleries that will run continuously around the year. The energy use as such is projected to be much higher than previously.

For example, multiple 4K (3840×2160 pixels) resolution multi-touch screens with projected capacitive touch technology and customized with interactive software are installed throughout the floors of the museum. Four of these are almost 2 meters wide and another six are 1.4 meters wide. These screens use LCD (liquid-crystal display) technology and consume more than 400 W each. All are embedded with NFC (near field communication) gateways. Embedded microprocessors operate each screen. These multitouch tables and touch walls are directly linked to the cloud collections and the artifacts currently on display. Another multitouch wall on the second floor reveals the architectural history of the Carnegie Mansion before it became the Cooper Hewitt. In a specially designed Immersion room, visitors can choose from examples of the Cooper-Hewitt's wall coverings collection, design and mix their own on a touchscreen table and project it to the surrounding full wall screens.

In addition to the media exhibits, the Cooper Hewitt introduced another piece of hardware to enhance its visitor experience. The Pen allows the visitor to collect and save design objects (digital) from around the galleries, and then transfers the collected objects to the touchscreen tables for further exploration. It is also connected to a dedicated web address that is personalized for the visitor where the visitor's collections are stored. Thus, the Pen not only brings together the media exhibits, the ticketing system and the digital collections, but also remediates the museum's cloud collections around the museum floor and beyond for augmented visitor experience.

Fig. 3.14. *Top*, A multi-touch table on the gallery floor. Photograph courtesy of Ideum; *bottom*, the Pen used to collect digital objects. Photograph courtesy of Cooper Hewitt Smithsonian Design Museum. All copyrights belong to CHSDM.

The media ecosystem within the galleries of the Cooper Hewitt have pushed the boundaries of display systems and associated technologies and created new unique experiences for the museum audience. But also it has increased the necessary media infrastructure and energy footprints to support such a museum-wide media exhibits system. Obsolescence is also guaranteed with regard to the large multitouch 4K displays as their lifespans are relatively short,[34] and new advanced OLED (organic light-emitting diode) technologies with higher pixel resolutions are already entering the marketplace.[35] This also implies a steady monetary and energy investment in upgrading media exhibit infrastructures to maintain ongoing accessibility to the museum collections and to ward off in-built digital obsolescence.

SOFT MEDIA INFRASTRUCTURE 3.5

COLLECTIONS MANAGEMENT 3.5.1

Collection management systems (CMS) are software programs designed to aid in the archiving and cataloging of objects in a museum collection. The Museum System(TMS), a proprietary collections management software based on the Windows operating system is a form of closed CMS. It is one of the most widely used collections management databases among contemporary art and heritage museums. TMS is intuitive for the average user, can be customized to a great extent depending on the museum's needs and has sophisticated tech support. It is adaptable and flexible to be used with contemporary art collections that may not fit into the "norm."[36] TMS is useful for coordinating large exhibitions with complicated loans and shipping. Although TMS is proprietary, a large number of institutional users exist in the museum field.

Digitization, conservation, digital labs and curatorial departments of the Cooper Hewitt use TMS in the daily processes of artifact acquisitions, digitizing, cataloging, adding metadata and generating conservation reports. TMS is also used for loans, external access, copyrights and to attach digital assets. From this internal database all other platforms including the cloud collections are based on. According to Chan, the collection management system is the master database of curatorial knowledge, provenance research, object labels and interpretation, public locations of objects in the galleries, and all the digitized media associated with objects, donors and people associated with the collection.[37]

But, TMS is not open source and relatively an expensive software. A database programmer is needed within the institution because of the necessary tweaking of the software and interface to adjust to the internal workings of the museum. Reporting is not intuitive and it requires an expert knowledge of SQL programming to be efficient.[38] All necessary customizations have to be tracked meticulously because they can be lost when TMS is upgraded. Exports and imports of digital assets can also sometimes be problematic. Data entry within TMS is cumbersome and complex and location tracking is extremely unwieldy. Finally, open source communities do not exist for discussions, hacks and resources.[39] All queries have to be assigned through the TMS's internal tech support.

3.5.2 CLOUD COLLECTIONS

Museums are storing and structuring collections situated in the Cloud, in remote servers located in Data Centers that are accessible through the Internet and negotiated using Application Programming Interfaces (API), laid on top of a digital collections database. The Cooper Hewitt has placed its Cloud Collections in the Amazon Web Services (AWS) Elastic Compute Cloud services and Rackspace cloud services. These are linked to its TMS collections that its base organization the Smithsonian stores in its Data Center in Virginia. The Cooper Hewitt has over 184 734 digitized heritage objects here, 74% of all of the museum's collections amounting to 2 Terabytes.

AWS's Elastic Cloud Compute services provide a flexible computing capacity for institutions and developers . One can control the available computing resources at any given time, allowing to quickly scale

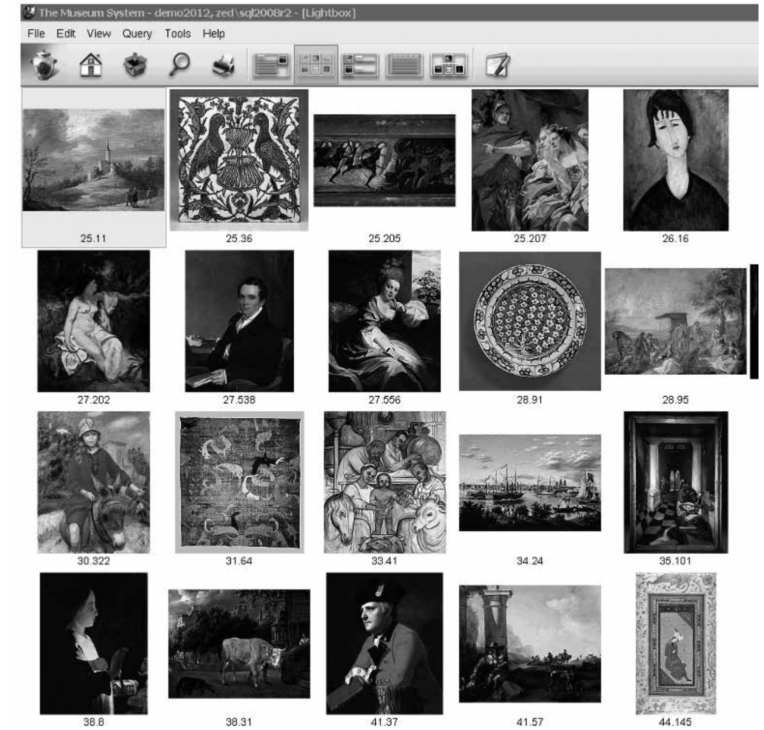


Fig. 3.15. TMS Interface. Screenshot courtesy of The Museum System.

up or down web operations.[40] The costs fluctuate, based on capacity and usage of elastic compute units (ECU) or 'Instances'.[41] The Cooper Hewitt API is the control point of the scaling operations. Amazon EC2 allows one to select a configuration of memory, CPU (central processing unit), instance storage, and the boot partition size that is optimal for the choice of an operating system and application.[42]

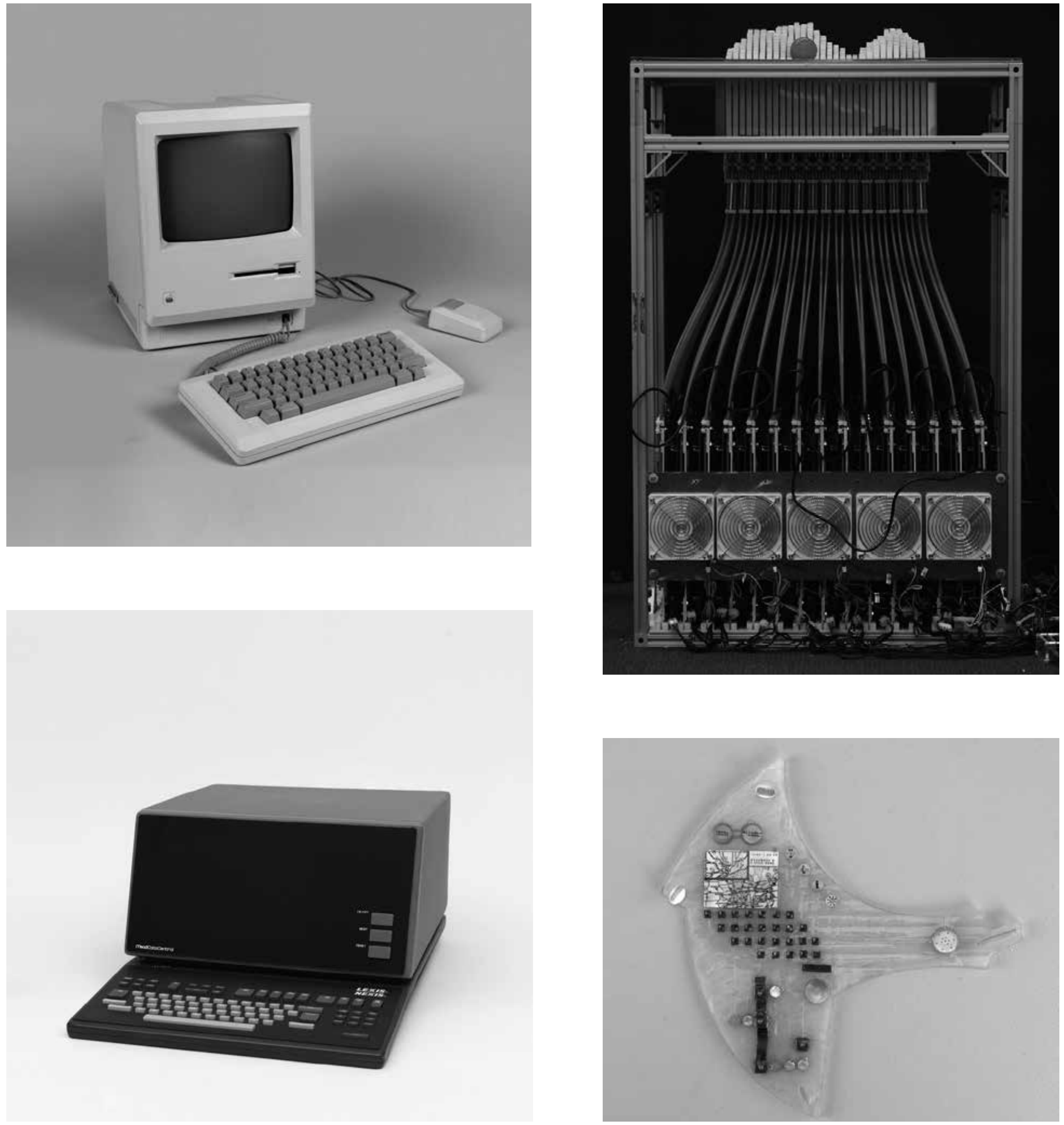
Amazon EC2 provides Cooper Hewitt with control over multiple 'Instances' for running applications. These virtual servers have different configurations of CPU (central processing unit), memory and storage. Thus based on Cooper Hewitt's needs Instances can be flexibly scaled, reallocated to various applications that the museum has deployed in its exhibition spaces and online.

3.5.3 APPLICATION PROGRAMMING INTERFACE (API)

An Application Programming Interface (API) is a particular set of rules and specifications that a software program can follow to access and make use of the services and resources provided by another software program that implements that API. In other words, an organized way for two machines (or programs, websites, apps, etc) to talk to each other or exchange data.[43] Usually APIs are built to attract third-party developer innovations, to monetize datasets, or to connect to mobile and connected devices. Museums such as Cooper Hewitt have enormous amounts of heritage datasets that can be manipulated with and applications and tools built to negotiate them.

Fig. 3.16. Collection Wall (2014) of the Cooper Hewitt Smithsonian Design Museum. Screenshot by author.

Fig. 3.17. *Top left*, personal computer by Apple Computer, Inc., 1984; *top right*, inFORM, a dynamic-shape display that gives physical form to digital information, 2013; *bottom left*, "UBIQ" Computer Terminal, 1997; *bottom right*, Prototype for wrist computer, 1988.



APIs have been in use since the early 2000s. Publishing user generated content, and the sharing of web links, photos and other media via APIs emerged with the birth of new social platforms between 2003 and 2006.[44] For example, "Flickr quickly become the image platform of choice for the early blogging and social media movement by allowing users to easily embed their Flickr photos into their blogs and social network streams." Facebook allowed developers to build social applications, games, and mashups with the new development tools. The Google Maps API demonstrated the incredible value of geographic data and mapping APIs. Museums including the Powerhouse Museum in Australia (one of the pioneers in museum APIs) thus started looking to how best link their digital collections to the social networks, since APIs make valuable resources modular, portable and distributed, making them a perfect channel for developing mobile and table applications of all shapes and sizes.[45]

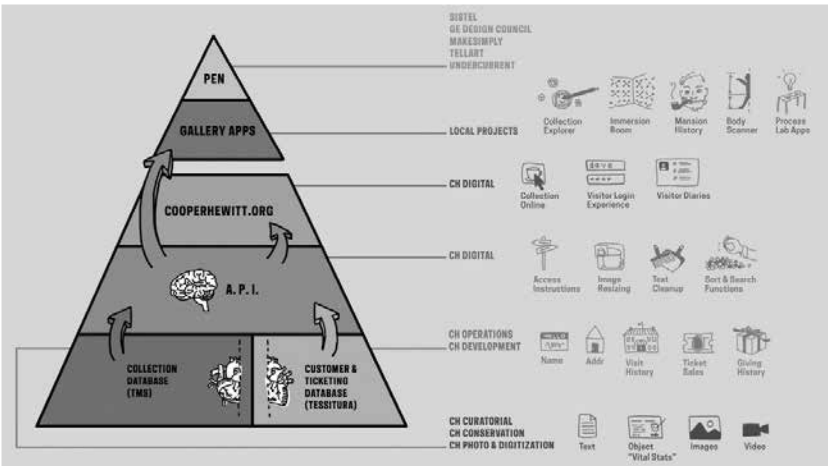


Fig. 3.18. The API Stack of Cooper Hewitt, Illustration by Katie Shelley (2015). Image courtesy of Cooper Hewitt Smithsonian Design Museum. All copyrights belong to CHSDM and Katie Shelley.

According to Chan, the Cooper Hewitt API operates as a virtual transportation system between the web and both the collections and Tessitura, a ticketing software system.[46] It also enables a set of other functions such as data cleanup and programmatic enhancement for the museum. The API contains not only methods for collection access but also user authentication, account structures, and anonymized event logs.[47] The public website is placed on the web layer, but also internally, there are web applications for the museum for maintenance. These other applications are built upon the API to assist with object label generation, metadata enhancement, and reporting. Cooper Hewitt also provides a REST application programming interface (API) for developers to develop apps on top of the museum's collections.[48]

According to Chan and Cope, the public face of the museum: cooperhewitt.org website is another instance (a 'scaffolding') similar to the API built around the core collections. From here one can enter the Collections and interact with the available data without dealing with the API. The Cooper Hewitt public (marketing) and collections website is built on Wordpress, an open source content management system based on PHP programming language,[49] and MySQL an open source database management system.[50] They both use the internal collections management system as the primary datasource.

At Cooper Hewitt the API and exhibition galleries are tightly intertwined. All the media exhibits are directly linked to the Collections API: the visitors can browse the design artifacts from the multitouch tables using the Pen. The Pen itself also has an ecosystem of applications related to its hardware that is connected to the API. All this means that the museum itself is the biggest user and beneficiary of its own API.[51]

TICKETING AND VISITATION 3.5.4

Visitation is an important metric for the Cooper Hewitt. The museum uses Tessitura, an enterprise software that uses a single database of information to record, track and manage all visitor data.[52] It also handles all membership transactions and provides detailed performance reports. Tessitura operates as a ticketing system database for the museum and in the case of the Collections API operates as an identity-provider where needed to allow for personalization of experience.

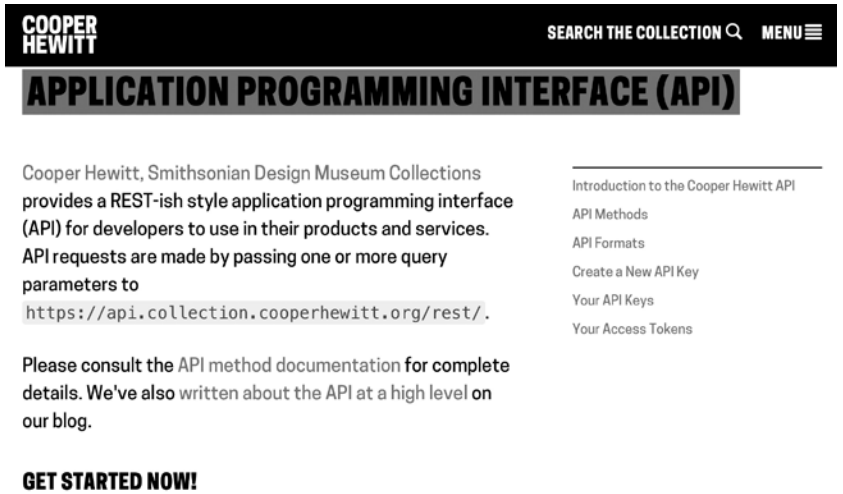


Fig. 3.19. The Collections API. Screenshot by author.

Tessitura at its most basic form, allows the museum to sell tickets online. The 'Tickets' website is written in PHP programming language and uses a MySQL database.[53] The Tessitura API has a designed 'wrapper' i.e., a similar graphical interface based on the Cooper Hewitt Collections API. The 'Tickets' interface is a REST-API,[54] based on Flamework PHP frameworks and uses oAuth2 for authentication.[55]

The ticket is also tied up with the Pen and eventually all the media exhibits. "A ticket generates a special barcode that gets paired up with the internal ID of the pen and that pairing gets stored in a database."[56] After the museum visit, one can use the code to connect back to a personalized webpage containing all the design objects collected using the Pen during the visit. Thus, according to Chan and Cope, the ticketing software that is a pre-visit tool continues to generate a post-visit 'persistence of visit'.[57]

3.5.5 MEDIA EXHIBITS

The Cooper Hewitt has extensive media exhibit hardware placed for complete digital immersion within its gallery spaces. This allows all

Fig. 3.20. The multi-touch interface. Photograph courtesy of Cooper Hewitt Smithsonian Design Museum. All copyrights belong to CHSDM.

the collections objects (only around 700-800 physical objects can be displayed at any given moment) including the digital collections to be viewed at the same time within the museum floor. The software platform for the exhibits is customized for the museum and intended to be synchronized with its online collections API. The Pen serves as a bridge between the Collections API and the media exhibits.

The multi-touch table in the Immersion Room allows visitors to browse the wallpaper collection of the Cooper Hewitt and simultaneously project it onto the walls of the room, recreating the immersive physical experience intended by the wallpaper's designer. In the other galleries, the multitouch tables display a stream of digital icons flowing in the middle representing artifacts from the collection: vases, wallpaper swatches, drawings.These can be manipulated at random by dragging them to a side of the table, zoomed in and used for looking up further information, as well as related items. Several visitors can simultaneously explore high resolution images of design objects. One can also draw a random shape that will bring up a related collection object.

All the multi-touch tables in the galleries and the Immersion Room use Gestureworks, a powerful authoring platform for multi-touch devices, sensors, and motion gestures.[58] Gestureworks supports over

300 multitouch gestures and a markup language such as XML (Extensible Markup Language) for multi-touch and motion recognition. The language is used to define touch gestures that describe interactive object behavior and the relationships between objects in an application.[59] "A description of multitouch gestures requires the system to report complementary touch information, such as position, motion velocity, and acceleration, for each contact point. The software interprets such information to recognize touch gestures and activate the associated action."[60] The large multi-touch surfaces in the museum also allow whole-hand gestures thus allowing a wide variety of interaction for visitors with the applications and the collections API.

Finally, as earlier discussed in sections 3.4. and 3.5.4., the Pen forms an integral part of the media exhibit environment of the museum. It is the device that is used both for interaction with and connectivity to the multi-touch tables and screens to the Cooper Hewitt Collections API. The Pen has an embedded NFC (near field communications) reader and dedicated onboard memory.[61] It works on a dedicated and closed application developed by Sistelnetworks. It allows bi-directional data transfer over NFC, i.e. one can collect data from custom reader boards on the multitouch tables and deposit data at registration stations. This allows a visitor to 'collect' design objects from around the galleries and compile their own collection that can then be later browsed online.

3.5.6 FACILITIES & OPERATIONS

Smithsonian's Office of Facilities Management & Reliability uses IBM's Tririga Computer Aided Facility Management (CAFM) platform to assist in the day to day operation, management, and maintenance needs of Smithsonian Facilities.[62] The CAFM allows to draw together a facility's data into a central location.

The Smithsonian also uses infrared (IR) imaging to evaluate structural building envelope performance, perform roofing assessments and evaluate energy conservation measures.[63] It uses IR imaging to provide real-time evaluation of mechanical and electrical equipment relied on for the preservation of artifacts, collections, and buildings.

"This technology allows for both predictive and preventive maintenance by providing quick and accurate inspections that translate into scheduled shutdowns of failing equipment, repair criteria, and planned resource management."[64] The application of IR imaging data results in well-documented infrared surveys and reporting information, including comprehensive photographic documentation and guidance for repairs. This data is utilized by the Smithsonian to make necessary facilities updates, changes, and repairs.

Fig. 3.21. The Smithsonian utilizes infrared imaging to evaluate structural building envelope performance. Photograph courtesy of Smithsonian Institution. All copyrights belong to the Smithsonian Institution.

For the renovation project, the architects and engineers have used Building Information Model (BIM) to renovate, chart and energy model the building. BIM tools are used to assist in the design and operations management of museums. The BIM software is capable of representing both the physical and intrinsic properties of a building as an "object-oriented model tied to a database".[65] A Building Information Model represents a digital three-dimensional repository of information of a building. It involves incorporating a museum building as a combination of objects that are themselves defined as parameters and relations to other objects in the model, and thereby, if any related objects are modified, then the dependent ones also get changed. The BIM process is able to construct a dynamic database model of a museum building that can be adjusted parametrically, edited across various scales, across several layouts with the editing of any one parametric object. A whole museum may effectively be visualized including its interior spaces, volumes, surfaces and components.

The Cooper Hewitt museum can be monitored using various energy analytics tools such as First Fuel Analytics.[66] First Fuel Analytics provides a detailed breakdown of end use of energy. In order to implement this software, the Cooper Hewitt has installed interval meters inside the Carnegie Mansion. These meters update as frequently as every 15 minutes, capturing tens of thousands of data points each year where the old, monthly-read meters captured just 12.[67] First Fuel determines the hourly local temperature and precipitation and gets satellite imagery to determine a building's shape and position relative to the sun. According to Fitzgerald, combining those data, its software is able to deduce what's been happening inside the building publishing a report of how it consumes electricity across nine categories, including cooling, electric heating, lighting, pumps, and plug usage.[68]

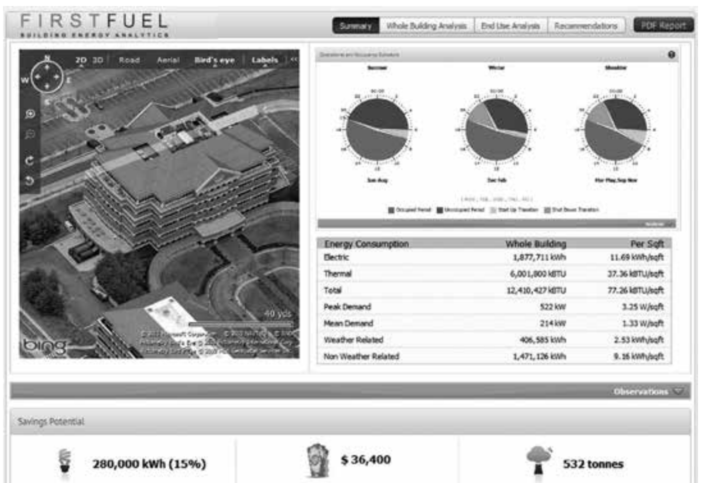


Fig. 3.22. Energy analytics interface by FirstFuel. Photograph courtesy of FirstFuel Software. All copyrights belong to First Fuel.

THE VIRTUAL MUSEUM 3.5.7

Recently, the entire Carnegie Mansion was mapped into a 3d model using Lidar during the renovation. A scanning team from 3dSystems captured 3-dimensional data from various spaces and structures of the building. Lidar is a remote sensing technology that uses a remote sensing device to measure distances using reflected lasers. The resulting data can then be uploaded to a computer to form a cloud of points, each representing one distance. When joined together, the points create a mesh that forms an initial working surface. A textured surface is then matched to the points from hundreds of pictures, ultimately creating a fully detailed and colored replica.

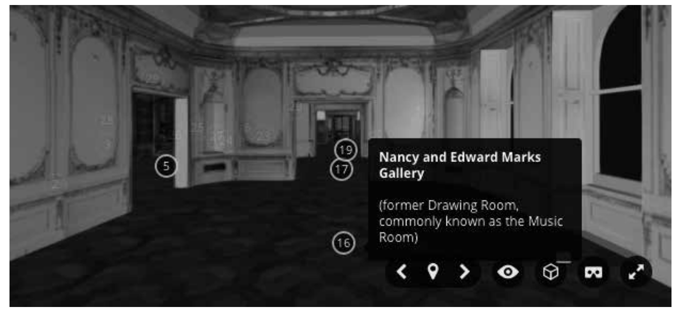


Fig. 3.23. 3D model walkthrough of the interior of the museum. Photograph courtesy of Sketchfab. All copyrights belong to Sketchfab.

Using Geomagic Solutions products, a team of artists and engineers transformed the real world Lidar scan data into data sets for 3D visualizations and 3D printable files.[69] Although not implemented yet, this 3D model builds towards virtual access to the museum spaces, exhibition planning and architectural study. The goal in the future would be to synchronize the 3d model with the museum's collections API.

OPERATIVE CONCEPTS 3.6

Several innovative methods were extracted from our analyses of the hard and soft media infrastructures of the Cooper Hewitt. These methods and concepts drive the relations between its material and media infrastructures. The primary method or concept is that of the design and implementation of the application programming interface (API) that provides a gateway to Cooper Hewitt's 'open' collections. This combined with the negotiation of artifacts in the museum through tangible user interfaces (TUI) forms the next layer of connectivity and interactivity. Adaptive reuse to house new media technologies into the mansion is finally the key to link visitation and interaction with the collections of the museum.

3.6.1 OPEN APPLICATION PROGRAMMING INTERFACE (API)

An API seems to be an essential requirement for any museum with digital collections. It is a key infrastructure that stays invisible, but allows a museum to centralize and propagate its digital collections and resources. On the software level, it encourages to build web applications on top, install collection tracking methods, visitation and ticketing and provides granular control of the collections for the museum personnel. A well-built museum API allows outside developers the chance to add their own talent and wealth to our data.[70] It also opens up possibilities of data visualization for artists and researchers.

At the Cooper Hewitt, the API and the exhibition galleries (including the multi-touch tables and other media exhibits) are closely synchronized. The two public-facing gallery layers are built by third party developers. "The application and interfaces are designed and built on top of the API, the Pen's ecosystem of hardware registration devices, and then the Pen itself which operates as a simple user interface in its own right."[71] The API operates as a linkage between the public (marketing) website, the collections and Tessitura, the ticketing system. The API also enables a set of other functions such as data cleanup and programmatic enhancement. It contains not only methods for collection access but also user authentication and account structures, and anonymized event logs.[72]

Building an API can result in long term efficiency for a museum. Here the process of building an API, the maintenance of digital collections and its web propagation itself is a hands-on learning experience for the personnel. By this process, new concepts can be tested and quickly prototyped in-house without exposing to the public. However, the API is specifically designed to operate on technologies of cloud-based hosting. Without dedicated cloud computing services, or in the event of a downtime in a data center could result in the media exhibits of the museum to become ineffective. Building an API requires substantial programming resources, web developers, digitized collections and a museum's willingness to open up the licensing and share its collections openly on the web.[73] According to Chan, the costs and resources to build an API can be easily made up for in future savings. Where it might be prudent to take short cuts and create a separate database here, a black box content library there, the fallout would be unchanging future experiences unable to be expanded upon, or, critically, rebuilt and redesigned by internal staff.[74]

TANGIBLE USER INTERFACES (TUI) 3.6.2

Tangible User Interfaces (TUI) are forms of user interfaces met when we interact with computer systems where the digital information is presented through natural forms and shapes in the form of graspable objects and augmented surfaces. TUIs have low threshold levels for beginners to participate and basically, it is about creating physical interfaces out of everyday objects.[75] We could refer, for example to "the case of a 'tangible' interactive exhibit presenting easily and accessibly the cultural content with which it deals addressing to users, regardless of their age or knowledge background."[76]

The Cooper Hewitt, even in its expanded form, "is a physically small museum and if interactive experiences were to support a transformed audience profile with more families and social groups visiting together, the museum needed experiences that worked well with multiple users, and provided points of social interaction."[77] Thus Cooper Hewitt deployed several TUIs on the floor of the museum to bring about expanded interactive connected experiences within a small space. These TUIs include the Pen and the multitouch tables for browsing and interacting with the digital collections.

The Pen has an embedded NFC reader, hence an 'active' pen. It can be used as a stylus not only for direct manipulation of content but also unlocks content from object labels, and enables new interactions with digital collections— "it can couple artifacts and surfaces to the correlated digital information, whereby the physical representations of digital data serve simultaneously as interactive controls." It is also location dependent within the museum building and is part of the holistic museum experience. The Pen is thus a key ingredient of the 'persistence' of visit experience, i.e. the artifacts collected from around the galleries are transferred to a personalized web address for the visitor where the visitor's collections are stored.[78] This enables as a post-visit 'memory-bank' of the digital collections for the museum visitor.

The multi-touch tables provide interactive experiences to multiple users simultaneously making efficient use of the small space of the museum. Multi-touch is one of the dominant input modalities in pervasive computing.[79] These tangible input devices encourage multi-user interactions by providing a touch interface to enhance the interactive experience. The use of multitouch tables for manipulating collections also changes the perception and interaction with their representations. The physical affordances of TUIs indicate the potential of multi-modal user interfaces to support cognitive activities.[80] In the future, a wide range of sensorial dimensions, such as 3D surround sound, language and gesture, could encourage the development of advanced user interfaces for museums.[81]

The Cooper Hewitt now is greatly dependent on a material and media infrastructure that supports the multi-touch tables and the Pen. It has to rely on dedicated cable networks to relay the collections database onto the TUIs inside the museum building. The requirements demanded by the Pen and related infrastructures impacts every layer of the museum's staff, its physical plant, its budgeting process and its day-to-day operations.[82] The multi-touch TUIs also have high emergy and require considerable electrical power to be run throughout the year. Finally, they have a short life span in context of the rapid advancements in screen technology and face obsolescence in the coming years.

OPEN COLLECTIONS 3.6.3

Cooper Hewitt's 'openness' character derives from its copyright-free collections (37 000 upwards) that have been digitized and organized under the open API. All Collection data (except images) is released under Creative Commons CC0 1.0 Universal (Public Domain Dedication) license.[83] The data is also available as a downloadable spreadsheet, as individual JSON (JavaScript Object Notation) files,[84] and through the open API. Developers can build third-part applications on top of the open API. Cooper Hewitt also maintains a Github account with freely available tools and in-house written software.

Although, as of 2015, the Cooper Hewitt collections data are open and freely available, the collections themselves are still to be scanned for their provenance and history. These were bought by the Smithsonian in 1968 and consists of mainly decorative arts collections originally assembled for the Cooper Union by the Cooper and Hewitt families.[85] The majority of the collections officially are out of copyrights and subject to 'Fair Use' under United States Copyrights Law.[86] But the museum has inventoried its collections and decided to have separate classifications of digital images of objects under separate copyright applications based on the years acquired and creation dates, as Table 3.1 shows.[87]

TABLE 3.1. List of acquisitions by date and related copyrights (Data source: Cooper Hewitt Labs[88])

CATEGORY	ACQUISTIONS	NO.
A	Acquired before 1923	32 442
B	Acquired on or after 1923 and known creation date before 1923	5 232
C	Acquired on or after 1923 and no known creation date	136 372
D	Acquired on or after 1923 and knowncreation date on or after 1923	30 357
E	Loan objects	13 477

Accordingly, Category A and B have no known copyright restrictions. These images could be used in compliance with the Smithsonian Terms of Use[89]. Category C and D and E may be subject to Copyright or other restrictions. Fair use is allowed under U.S. Copyright law and in compliance with the terms of use. The onus is on the user to determine whether use is fair and for responding to any claims that may arise from use. Many of the 'utilitarian objects' in the collection such as clocks, tables, chairs, much of the product design collection are legally untested in terms of whether Copyright applies, however in many of these cases other IP protection may apply.[90] Yet, almost over 37 000 design objects from the Cooper Hewitt collections are under no copyright restrictions and are freely available from the collections site.

Cooper Hewitt states in its mission of a long-term commitment to an open strategy when it comes to its collections, knowledge and resources. The commitment to open collections drives the push for openness in other parts of the museum, namely in the public API. However, this strategy does not extend to its massive media infrastructure supporting the open collections on the floor of the museum, a majority of which is proprietary.

3.6.4 ADAPTIVE REUSE

According to Abramson, for much of the twentieth century, architectural change was imagined as the process of obsolescence, new superseding old, devalued and made expendable. He says that architects and others both embraced and recoiled from shared perceptions that obsolescence characterized modernity, imagining short-life buildings on the one hand, insisting upon permanence on the other. Here, "obsolescence, came about as a result of changing technology, economics and land use, in which the new would inevitably outperform and devalue the old."[91]

As a result a wave of demolition had swept New York and Chicago in the early twentieth century when large numbers of buildings were deemed 'obsolete'. The Carnegie Mansion and the gilded mansions of its age survived this wave merely due to their affiliations with industry leaders and the fact that we were well maintained and also beyond the range of land use boundaries. Thus, Lange says that, "at a time when so many museums seem intent on new spaces for new design and new art….it's a relief that the Cooper Hewitt spent the time and the money to make the 1902 Carnegie Mansion sing. Rather than being a straightjacket, the mansion's ornate rooms and halls now form a rich and idiosyncratic frame for design objects of all ages."[92]

Retrofitting an old building, that too a historically protected structure, and fighting obsolescence to include new media is a major challenge. The original remodeling was done in 1976 to convert the residential layout to a public gallery for displaying design objects. The recent renovation has gone a step further in incorporating advanced media infrastructures within its walls and floors, new vertical transportation systems and concealed HVAC systems under the roof. The hardware infrastructure needed for the numerous multitouch tables, vertical touch screens, projections, lighting schemes and revamped air-conditioning required a detailed analysis and design for the renovation of the internal structures of the building.

Simultaneously, the new design enhanced the original character of the mansion without changing the historic nature of the spaces. The re-modeled Cooper Hewitt is a classic example of adaptive reuse, that of Carnegie Mansion, an old historic residential building to a digitally embedded museum building.

INFRASTRUCTURAL ENERGY ANALYSIS 3.7

OVERVIEW 3.7.1

An estimation was initially made of the media infrastructure of the Cooper Hewitt. This included the possible computing hardware, interfaces and devices (some of the data was collected during the research visit and others through literature studies). Although this may not be entirely accurate, the point of this exercise was to approximately quantify the energy and emergy of the museum to raise awareness about the issue. As already introduced earlier in 2.3, two components of the museum's energy are its embodied energy or emergy (the energy required to build the devices of the museum's infrastructure) and the other is the electricity use. In the limited scope of this study however, the emergy of artifact collections were not considered. Nor have we calculated the emergy of the museum buildings.

3.7.2 CENSUS

First, the end devices were considered in this study. This included laptops, desktops used in the daily museum administration and management. Then, the Cloud servers situated in the museum and the data center. Smartphones belonging to the personnel were also included. Second, infrastructure devices such as routers, Local Area Network (LAN) devices and telecommunication devices were considered.

It has been estimated that each personnel has access to an institution-issued desktop, laptop and smartphone. 1 in 2 persons have access to a tablet. Administration includes the Director's office and miscellaneous administrative offices; Security includes the entire campus security and Digitization includes the library, photo studio, storage, library, server room at Newark.

The census shows the prevalence of back-house desktop computers and mobile technologies that constitutes over 50 percent of the overall media infrastructure. Media exhibits, from the public side forms only 2 percent.

3.7.3 EMERGY

As discussed earlier in 2.3, the calculation of emergy is – "a complex process that involves considering the energy used during the manufacture of devices, the contribution from components and materials of the device, and recursively the emergy of those components and materials."[93] All end devices are enumerated in Table 3.2 and their corresponding emergy. These units have been gathered from a number of studies.

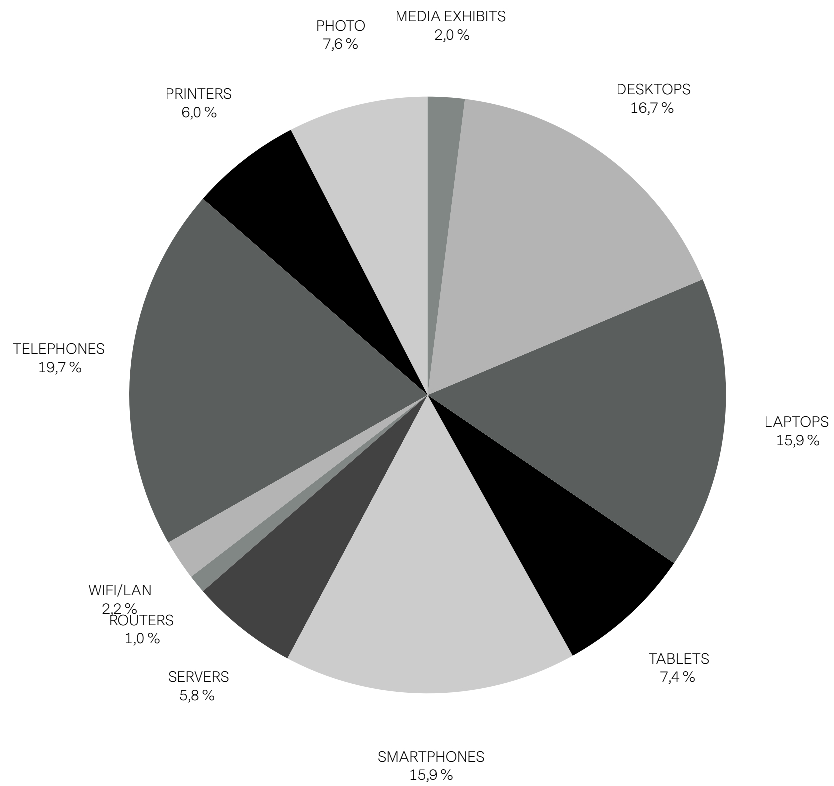


Fig. 3.24. Census Chart of media infrastructure of the Cooper Hewitt Smithsonian Design Museum as of 2014-15.

Note: A gigajoule (GJ) is equal to one billion (109) joules. A Joule is a unit of energy in the International System of Units. It is the energy dissipated as heat when 1ampere of electric current passes through a resistance of 1 ohm for 1 second.

From the above calculations, the total emergy of the media infrastructure of the Cooper Hewitt was found to be approximately 1595,5 GJ. Compare this to an american household that utilizes 100 GJ in a single year.[95]

Table 3.2. Emergy of media infrastructure of the Cooper Hewitt[94]

CATEGORIES	NO.	PER-UNIT EMERGY Gigajoules (GJ)	TOTAL EMERGY Gigajoules (GJ)	REPLACEMENT TIMESPAN (years)
Desktops	84	7,5	630	4
Laptops	80	4,5	360	3
Tablets	37	2	74	3
Smartphones	80	1	80	2
Servers / Storage	29	5	145	3
Routers	5	1	5	3
WiFi / LAN	11	1	11	3
Telephones	99	0,5	49,5	4
Printers	30	0,5	15	3
Photographic	38	2	76	4
Media Exhibits	10	15	150	4
TOTALS			1595,5	

3.7.4 ENERGY CONSUMPTION OF HARD & SOFT MEDIA INFRASTRUCTURE

The energy consumption of hard and soft media infrastructure has been collated in the following sections. As discussed earlier in 3.2, we examined two sets of materialities embedded in the Cooper Hewitt museum infrastructure, one that was expressed in the architecture, the tangible devices (hard) and the other that existed in the computing languages (soft), that negotiated the museum's digital content. Thus, the museum was analyzed by hard and soft media infrastructures and resulting from that analyses we derived infrastructural energy data.

A. Energy Consumption of 'Hard' Media Infrastructure

i. Mansion / Museum Building: When the Carnegie Mansion was built on the upper reaches of Manhattan between 1899-92, more than 30 companies were generating and distributing electricity throughout the boroughs of New York City and in Westchester County.[96] Today the energy is distributed by Con Edison. A shown in Figure 3.24, towards the end of the renovation phase, early in the 2nd Quarter of 2014, the Carnegie Mansion consumed on average 650 mmbtu or 190,5 kWh far above the CBECS Benchmarks.[97] The Carbon Footprint exceeded 1316 cars/ year or 6.25 Metric Tons.[98] This data was however not a good representation of the actual energy usage for the facility, due to the ongoing renovations. A normalized representation is expected once the museum has been open for a few quarters.

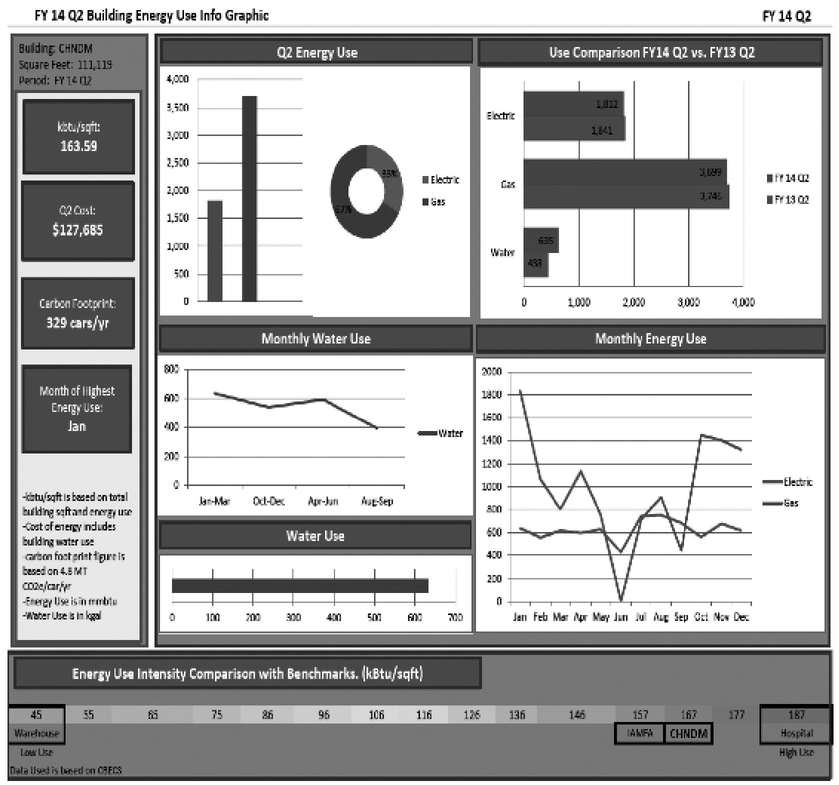


Fig. 3.25. Utility energy use in the second quarter 2014 when the museum was under renovation. Illustration courtesy of Cooper Hewitt Smithsonian Design Museum.[99]

The Mansion has been awarded a USGBC's LEED Silver certification, a rating based on set of criteria for ecologically friendly construction.[100] According to Cooper Hewitt, LEED achievements include: "Recycling and/or salvaging 75% of construction waste and creating a construction waste management plan. Optimizing energy performance by 10.5% - 14%. Purchasing green-e-certified electricity supply for 2 years, for 35% of the building's electricity demand. Reducing water use by 40%.

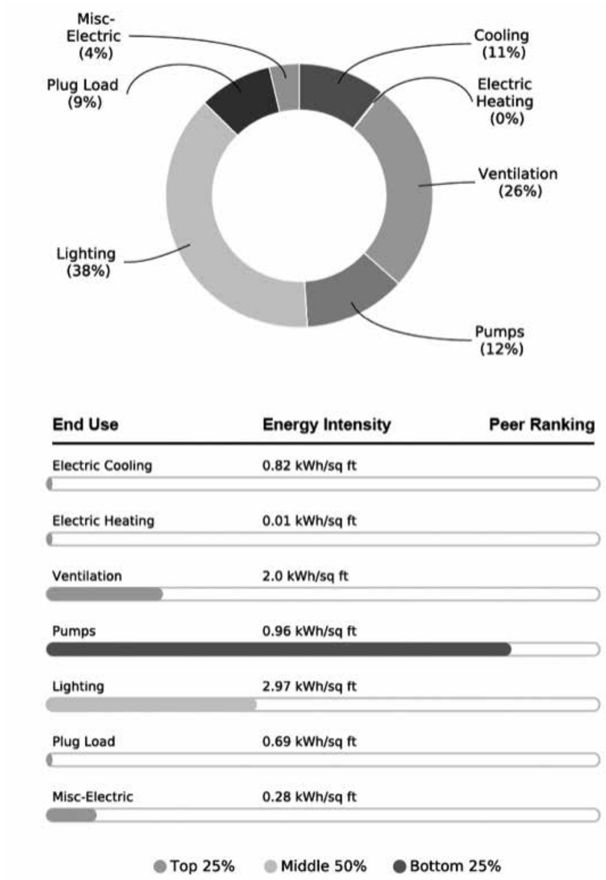


Fig. 3.26. Annual energy use between 6/1/2014 to 5/31/2015 classified by major usage categories. From Rapid Building Assessment Report for Cooper Hewitt Mansion & Miller Fox House, 10/26/15, by FirstFuel. Illustration courtesy of the Cooper Hewitt Smithsonian Design Museum. [101]

Not visible but crucial to the project were the careful integration of many mechanical system improvements including: lighting, air conditioning, plumbing, electrical, fire protection, security and data infrastructure throughout the building, as well as the discreet introduction of fire sprinklers throughout the Mansion's main floors." The Smithsonian monitors energy consumption and costs quarterly. It currently does not break down usage by end use. However, as of late 2014, First Fuel, an energy dashboarding and analytics software was being tested which would give a detailed breakdown of end use of energy.[102] In order to implement this software, the Cooper Hewitt has installed interval meters around the museum building.[103]

The energy reports show an annual consumption of 7,73 kWh/sqft. For 17 000 sqft, this amounts to 131 410 kWh or 131,41 MWh (megawatt-hour). By the month, CHSDM consumed 10,95 MWh.

ii. Conservation & Storage Facility: The energy requirements for '3 West' come from the Public Service Electric & Gas Company and eventually from Constellation Energy Resources.[105] Here, the wall-mounted Circular Chart Recorder is usually set between 40 and 48 RH. The wall-mounted recorder is microprocessor-based and capable of measuring, displaying, recording, and controlling up to two process variables from a variety of inputs. These process variables include temperature, pressure, level, and flow. All climatic data can be monitored and recorded. The levels maintained here are quite stringent, much more regulated than prevailing International Standards such as ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers), EU's Committee for Standardization and UK British Standards Institution (BSI).[106] As a consequence the energy bills are ranging in the thousand kWh mark.

iii. Media Devices: Here the calculations depict the normal electricity use of the various components of the media infrastructure, as listed in Table 3.3. The energy values have been gathered from various sources.[107] The duty cycle assumes the duration of the use of the device, for example desktops are used half the time whereas, servers are always on.

B. Energy Consumption of 'Soft' Media Infrastructure

i. Cloud Collections: The Cooper Hewitt's online Collections are

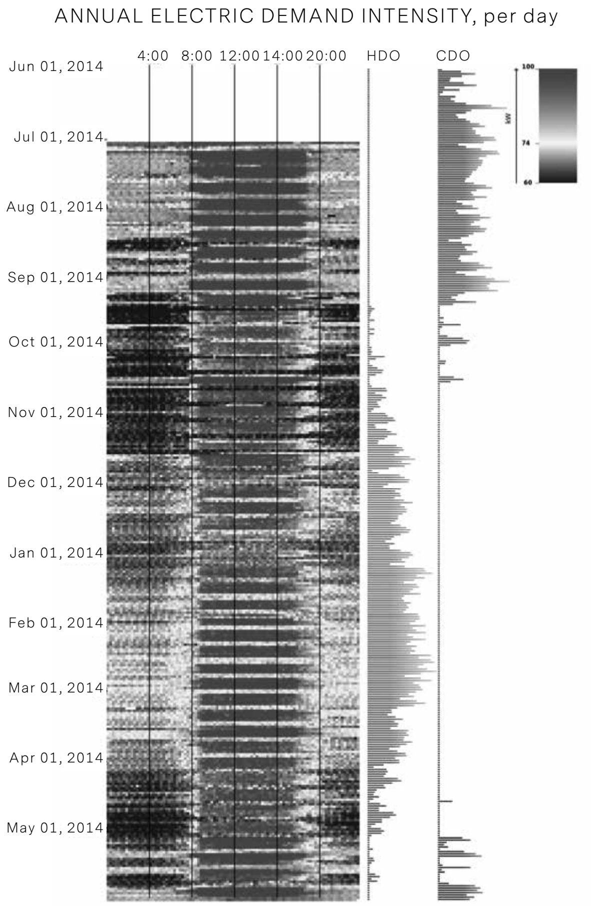


Fig. 3.27. Annual electricity demand intensity infographic (2014-2015). Horizontally the graph depicts the power consumption for each metering interval throughout each day. Red indicates high intensity intervals, whereas green indicates intervals of low intensity. Yellow indicates the average intensity. Recorded between 6/1/2014 to 5/31/2015, recorded in 15-minute intervals. From Rapid Building Assessment Report for Cooper Hewitt Mansion & Miller Fox House, 10/26/15, by FirstFuel. Illustration courtesy of the Cooper Hewitt Smithsonian Design Museum. [104]

Open Access. So for the digital Collections to be available online on demand at all times, the Cooper Hewitt depends on hosting its Cloud Collections API (Application Programming Interface) at Amazon Web

Service (AWS) that has a controversial track record in sourcing its energy requirements. 184 734 virtual design objects reside here, of which a small portion are born-digital. These constitute 74% of all the museum's collections, 2 Terabytes in the Cloud. According to a 2014 Greenpeace Report, although Amazon provides the infrastructure for a significant part of the internet with over 40 000 servers, it remains among the dirtiest and least transparent companies in the sector. It's data centers run on 28% Coal, 27% Nuclear, 25% Natural Gas and merely 15% Renewable Energy resources.[108] AWS is far behind its major competitors, such as Facebook or Google, with zero reporting of its energy or environmental footprint to any source or stakeholder. It chooses to power its infrastructure based solely on lowest electricity prices, without consideration to the impact their growing electricity footprints have on human health or the environment.[109] The Cooper Hewitt Cloud Collections on Amazon EC2 are essential for the web presence of the museum. It has a monthly online visitation of an average of one hundred thousand visitors (458 609 Website visitors in FY2015), half a million page-views from over a hundred countries worldwide. The total average monthly invoice is approximately 3000 US dollars.

ii. Smithsonian Data Center: The Smithsonian Data Center in Herndon Virginia contains over 1000 servers maintained by 100 personnel. The contents in its servers comprise digital heritage collections, scientific, and administrative data of the Smithsonian Museums including that of the Cooper Hewitt. Its Energy Reading in May 2014 was 1723 kWh (Average of 20 676 kWh annually). Equivalent to 1.2 Metric Tons of Carbon Dioxide Emissions. 134 Gallons of oil consumed, 1276 pounds of coal burned. Its UPS meter reading was 278 KW. About 0.192 Metric Tons. Together they clock carbon emissions of over 16.5 tons of CO2 annually. 13.6 acres of forests could only offset that. The calculations are based on U.S. Environmental Protection Agency's Greenhouse Gas Equivalencies Calculator.[110]

Within the Data Center, 2 Dell Poweredge servers handle the collections database of the Cooper Hewitt Smithsonian Design Museum's TMS database. It contains over 273 404 object records and 90 012

Table 3.3. Energy consumption of media infrastructure
Note: The values above are conventional wall-socket power estimates. The device duty-cycles are also estimated. Based on the above calculations, energy consumption of the media infrastructure of the Cooper Hewitt: 140 kilowatts-hour, whereas embodied energy is 127 megawatts.

CATEGORIES	NO.	WALL-SOCKET POWER	DUTY CYCLE	TOTAL POWER (AVERAGE)	
				Wall-socket (kilowatt -hour)	Embodied (megawatt -hour)
Desktops	84	150W	0.5	6,3	43,6
Laptops	80	40W	0.5	1,6	33,3
Tablets	37	2,5W	0.5	0,046	6,85
Smartphones	80	1W	1.0	0,08	11
Servers / Storage	29	375W	1.0	10,875	13,3
Routers	24	5kW	1.0	120	2,2
WiFI / LAN	11	20W	1.0	0,22	1
Telephones	99	5W	1.0	0,495	3,43
Printers	30	5W	0.5	0,075	1,38
Photographic	38	2W	0.25	0,030	0,48
Media Exhibits	10	80W	0.5	0,4	10,4
TOTALS				140,121	126,94

image records. 527 GB of disk space out of allocated 729 GB. And still growing. The Collections database is the backbone of Cooper Hewitt's daily museological operations. The servers assigned to Cooper Hewitt consume over 20 kWh/per month. A quick calculation shows that the carbon emissions is equivalent to 178 pounds of coal burned. This is the footprint of Cooper Hewitt's design heritage.

Several ongoing research studies are in progress to understand the energy efficiency and carbon footprint of data centers that host digital collections.[112] Measuring Energy-consumption of Digital Collections hosted in data centers is currently a challenge. Granular energy figures for a computing system would entail building an energy calculation model which is outside the scope of this study, but certainly relevant for the future.

Table 3.4. Electricity meter readings (2014) for the Smithsonian Data Center in Herndon, Virginia.[111]

DATE	NORTH METER (KW h)	CONSUMP-TION (KW h)	SOUTH METER (KW h)	CONSUMP-TION (KW h)	UPS METER (KW)	CONSUMP-TION (KW)
12/02/13	11,151		142,522		1,561,141	
Jan. 2nd	11,326	175	144,211	1,689	10,860,266	299,125
Feb. 3rd	11,559	233	145,793	1,582	11,143,966	283,700
March 1st	11,727	168	147,131	1,338	11,380,827	236,861
April 1st	11,911	184	148,786	1,655	11,672,718	291,891
May 1st	12,048	137	150,372	1,586	11,950,812	278,094

RESULTS 3.7.5

The Cooper Hewitt uses close to 10 MWh (10 000 kWh) of electrical energy every month. The average annual residential energy consumption in the US is 10 932 kWh or 10,932 MWh, an average of 911 kWh per month.[113] From our census and energy consumption analysis, we found that the computers and associated electronic devices consume approximately 140 kWh (compare this to the electricity meter reading of 650 mmbtu/190,5 kWh in figure 3.24). The total emergy of the media infrastructure of the Cooper Hewitt was found to be approximately 1595,5 GJ. These two quantities, the energy use and the emergy now demonstrate the complete energy footprint of the museum.

SUMMARY 3.8

We excavated and mapped the Cooper Hewitt by its material and media infrastructures and demonstrated the related energy footprints. We also analyzed several operative methodologies that were used to bridge the infrastructures. Our energy analyses shows that these methods are energy consuming and more so when the underlying structure and processes are invisible or hidden. Subsequently, the technologies used are proprietary, patented and are subject to obsolescence. Unfortunately, even the design and implementation of the media infrastructure was outsourced to third-party vendors which resulted in minimal knowledge gain for the museum's community itself. Thus, building Openness for the Cooper Hewitt came through complex infrastructuring and relatively at a high price.

Our studies in 3.7. show that the blackboxed domains of the museum are in fact concealing the most energy intensive processes. The media exhibits, and most technologies available and used by the museum are proprietary and not open source. The embodied energy required to build the blackboxed devices and collections infrastructure that comprise the Cooper Hewitt system is an un-explored realm. This could be particularly significant when it comes to life-cycle decision making, migrating to an open system and daily maintainance. Additionally, a steady maintenance of the collections hosted in high energy-use data centers becomes an absolute requirement for dynamic availability online at the cost of high energy-consumption.[114]

A majority of the media infrastructure of the Cooper Hewitt is subject to technological obsolescence. The swift evolution of digital technology in hardware, software and storage systems implies that a steady monetary and energy investment will be incurred by the museum in constantly improving infrastructures. This, to maintain accessibility to the museum collections and to ward off in-built digital obsolescence. All such initiatives necessitate a parallel and relentless infrastructural enhancing for the museum.

Utilizing third party vendors and not in-house creative talent for the design and implementation of the media infrastructure is not feasible for museum in the long run. Such methods discourage the museum's own community from understanding its own technology infrastructure and develop related competence. It also prevents the museum from acquiring skills through recruiting appropriate human resources as part of the museum's technology backbone. Without understanding the materiality of its own infrastructure, a museum cannot effectively enact strategies in the future to chart its technological course.

"Opening up" a museum is a complex infrastructural task. It requires a major transformation of museum infrastructure at various levels . A museum building retrofitted with appropriate infrastructure is at first needed. The media infrastructuring has to happen at both the hardware and software level. This involves not only technologies that are to be made available for digitization of artifacts, collections management and open APIs but also a substantial and perpetual upgrading of the material infrastructure of the museum.

NOTES TO CHAPTER THREE

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39 St. Laurent, *Understanding Open Source and Free Software Licensing*, 4.

40 Scalability of web operations refers to the capability of a computing system, network, or process to handle a growing amount of work (i.e. increased webpage visits, downloads, API calls etc.), or its potential to be enlarged in order to accommodate that growth.

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a 1.0-1.2 GHz 2007 Opteron or 2007 Xeon processor, also the equivalent to an early-2006 1.7 GHz Xeon processor.

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50 MySQL (Structured Query Language) is an open source Relational Database Management System (RDBMS) and a popular choice of database for use in web applications. MySQL is used by most social networks and large web companies such as Facebook, Twitter, Google, etc. MySQL can also be run on cloud computing platforms such as Amazon EC2. Many programming languages with language-specific APIs include libraries for accessing MySQL databases.

51 Chan, "The API at the Center of the Museum."

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53 See note 45 and 46.

54 REST is an acronym for Representational State Transfer. It is an architecture style for designing networked applications. The idea is that, rather than using complex mechanisms such as CORBA, RPC or SOAP to connect between machines, simple HTTP is used to make calls between machines. The World Wide Web itself, based on HTTP, can be viewed as a REST-based architecture. RESTful applications use HTTP requests to post data (create and/or update), read data (e.g., make queries), and delete data. See more: http://rest.elkstein.org; Flamework is a PHP web-application framework, born out of the processes and house-style developed at Flickr.com, see more: https://c9.io/micahwalter/flamework (accessed February 16, 2016); OAuth is an open standard for authorization, commonly used as a way for Internet users to log into third party websites using their Microsoft, Google, Facebook or Twitter accounts without exposing their password, see more: http://lifehacker.com/5918086/ (accessed February 16, 2016).

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101 Groom, email message to author, February 20, 2016.

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4

CRITICAL MAKING

4.1 INTRODUCTION

The Light is History project was conceived and built in context of Trashlab, a monthly event we initiated and organized in 2012. The aims were to explore practices in experimental art, design, technology among hacker and maker collectives, in the context of re/up-cycling and the increased availability of new fabrication tools.[1] Trashlab's objective is to establish a community of artists, designers, hackers, makers, re/up-cyclers, activists who are concerned with material and electronic waste, and tackle this problem through creative and tangential approaches. A lecture series called 'Talking Trash(lab) was arranged to complement the workshops on related topics such as the reuse of electronic waste, digital rubbish,[2] repair, fashion upcycling,[3] natural resources etc. Light is History was followed as a case-example throughout the year for the overlapping themes fostered by Trashlab.

In this design intervention, we attempted to simulate the infrastructure of the museum in a smaller scale in the public domain: an alternative museum powered by the community's energy savings.[4] We tried to simultaneously open up both the hidden museum processes and visualize the energy consumption issues. As mentioned in Chapter 2 (2.5), here we attempted a circuit-bending of the museum black box. Our goal was not only to build an alternative scaled open system that mimics the museum but also one that would engage community, generate awareness of energy consumption and promote wellbeing. We also considered whether visibility of the infrastructure increases 'openness' and reduces energy consumption in the long term? Could our project powered by the community serve as an alternative model to the energy-intensive museum?

For this we did an initial excavation, as dealt in section 4.2, a charting of the history of the electricity meter followed by an energy mapping of the community of participants of our project. Here, "excavation" establishes the context through an outline of the history of electrification, metering and the Nordic material culture, the field in which Light

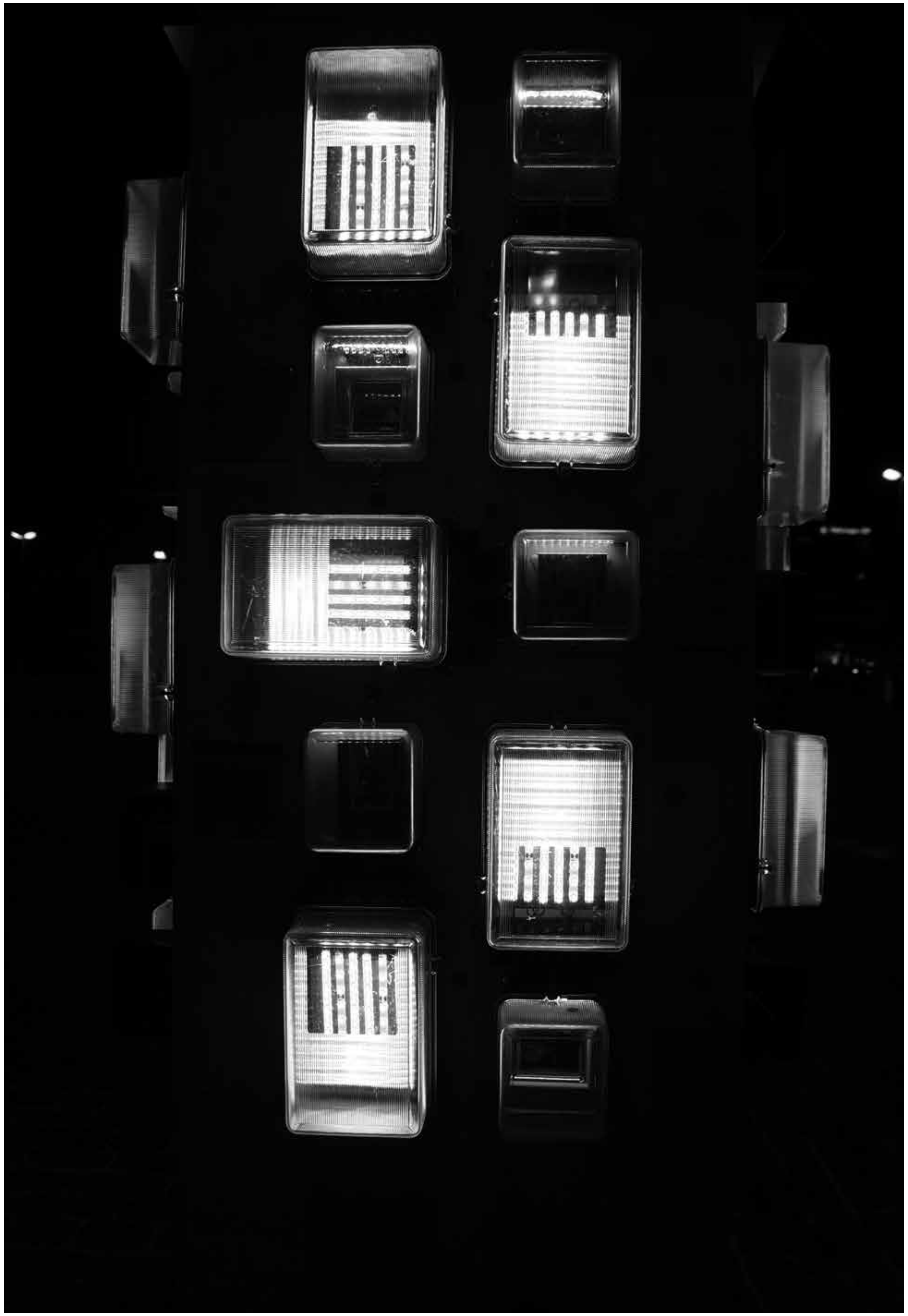


Fig. 4.1. The Light is History installation at Hakaniemi Market Square Helsinki.

is History is situated. We initially mapped the participant's homes in context of energy consumption that enabled us to understand and analyze their energy footprints and self-reflection that went into the publishing of their personal energy data.[5] We documented the participant's living spaces and the energy artifacts they used. Energy use was documented through layout sketches that included spaces that the participants considered to be of high energy and low energy consumption. We mapped their entire twenty-four hour cycle from waking up in the morning to going to bed. This mapping allowed us to explore and configure a process to exhibit the private energy lives and artifacts of the participants.

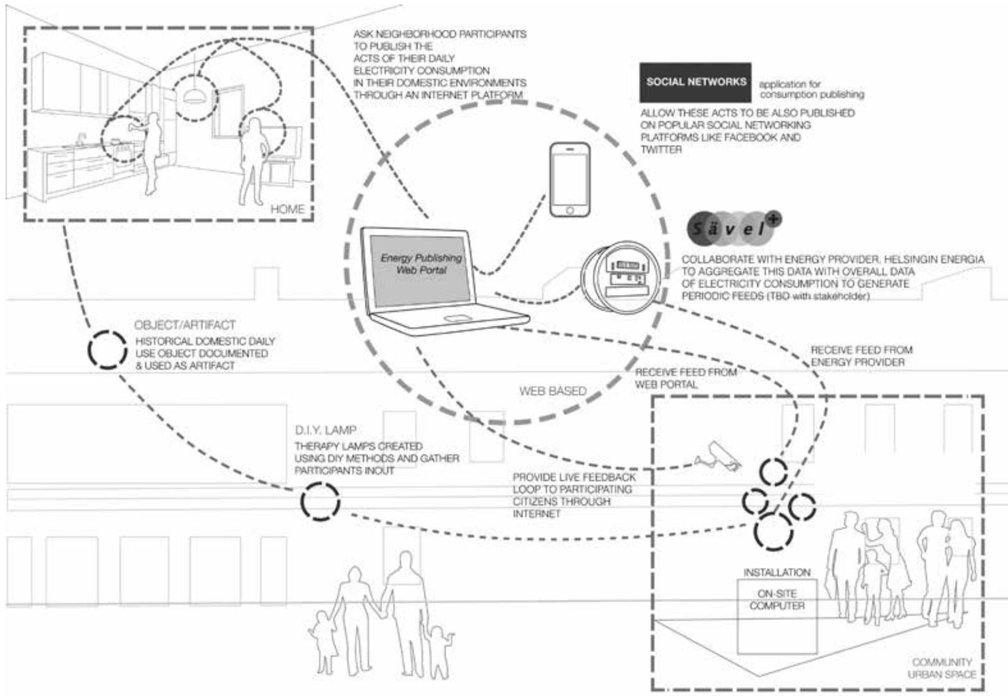


Fig. 4.2. Original System Diagram for Light is History. Adapted from an original illustration by Karthikeya Acharya.

Then we designed and built the necessary physical and digital infrastructure to foster the community's energy artifacts and narratives as shown in figure 4.2. The project's main underlying action that powered the infrastructure of the installation was energy use monitoring, energy saving and publishing.[6] We devised an alternative process, of energy monitoring that bypassed the local energy provider's metering devices and energy database. We repurposed old electric meters into therapy lamps and museum vitrines (these meters have been black boxed for ages and has been the privilege of the energy provider until the recent emergence of smart devices) and placed them in an installation. We wanted to examine how this community-participated museum installation would play out in a busy market square. Could sharing/publishing/visualization of energy data & material artifacts lead to behavioral change? Could it reduce the energy consumption of the participants due to public visibility of their daily energetic lives?

Based on what we initially examined in Chapter 2, one of the key methods we considered was Constructive Design Research, where the research method intended to imagine and build new things and describe and explain these constructions."[7] We hoped to find solutions and new approaches through prototyping, building and deploying the design intervention to explore and question current museum practices in the real world contexts.[8] However, during the self-reflective duration of the writing of the dissertation, our design intervention can be seen as being engaged mainly in 'Critical Making', "a mode of materially productive engagement….."[9] and "striking a balance between making and purpose, reflection and materiality to extend critical reflection on technology and society,"[10] in this case the electricity distribution, metering and material culture. Hertz's 'Tactical Reuse' methodology can also be seen in the repurposing of discarded electricity meters, with an underlying goal of challenging institutional structures, that of the energy provider.[11] By 'Circuit Bending', we broke open the blackboxed metering technology and reconfigured them as museum vitrines. 'Counter-remediation' happened in our project when these old media remediated the energy use into the unfamiliar outcomes of therapy lamps for public wellbeing.[12] During the installation, the community participants self-published their energy consumption to power the installation. Throughout the project we 'microstructured' the media, tasks and processes and to a great extent relied on open source technologies. We will later examine in detail all the methodologies including 'microstructuring' of the project in section 4.3.

The Light is History installation was supported by a minimal material infrastructure, as elaborated in section 4.4. Hard Media Infrastructure. Most of the materiality was composed of a wooden 'mainframe' and repurposed electric meters.[13] The four-sided square mainframe served as the primary large material interface in the public installation. The meters transformed as bright therapy lamps and vitrines were the main components of this interface. Inside the wood mainframe was sited a Arduino microcontroller that through a control algorithm communicated with over two thousand LEDs. The electrical artifacts of the community participants as photo documentaries were printed and mounted inside old wooden photo frames that were placed inside the 'vitrines'. Of all these, the microcontroller is the only concealed material infrastructure. This was due to a practical reason that we could not sufficiently weather-proof the installation and that the microcontroller would be climatically safer inside the protected mainframe. Given the resources, we would have exposed the entire infrastructure of the installation.

The soft media infrastructure (section 4.5) needed for initiating our project was composed of simple Wordpress website. We utilized several community forums during this stage to broadcast the project and gather participants. We also resorted to traditional media of printed posters to convey the project idea to the community. We built a web API (Application Programming Interface) that communicated between the participant's energy data and the Arduino microcontroller. We could not link the local provider's energy API to our API because of the provider's customer privacy and national security concerns as communicated to us in initial discussions. The control algorithm of the microcontroller was programmed to compute the meter reading entries and produce variable light intensities over the period of the installation. Finally, as part of the media infrastructure, an archive was constructed to house the digital images and personal narratives of the participants and their electrical artifacts.

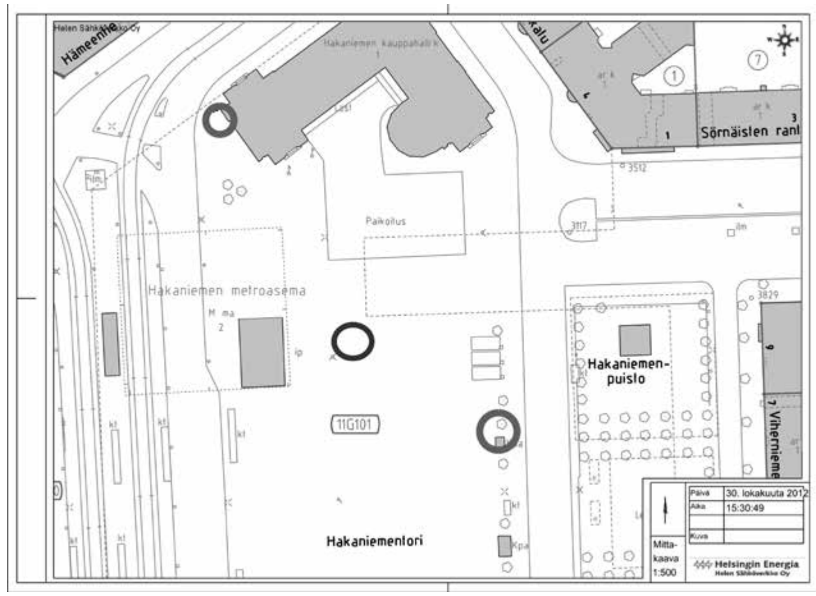


Fig. 4.3. Urban plan of Hakaniemi Market Square showing the public electrical connection outlets. The circle in blue near the Metro station was the final chosen spot for the project. Drawing courtesy of Helsinki Energy. All copyrights belong to Helsinki Energy.

As we shall see in section 4.6, prior to final installation, we simulated two variations in academic and public forums. This allowed us to test the viability of the project in terms of community feedback. The final installation was sited in the market square of Hakaniemi in Helsinki. Hakaniementori is a large plaza near to downtown that serves as an open market and public events for the local neighborhoods. It has a significant place in Finnish history, associated with worker's rights. The square is surrounded on all sides by transportation systems and is a major thoroughfare for pedestrians and bicyclists. After careful analysis of the market square we sited our installation next to the metro entrance, in midst of a pedestrian walkway and close to an adjacent electrical point of the energy provider. During the installation energy use publishing was carried out by the participants over a period of ten days and was used as the daily data set for the light intensities on the installation. The installation was operational every evening for a week gathering participants and the general audience of the market square.

Our infrastructural energy analyses in section 4.7 examined two facets of the installation's energy use. One was its electricity use and the other embodied energy (emergy)—the energy needed to construct the devices and infrastructure that comprise our project. The analyses show a low energy-consuming installation with low-embodied energy material and media infrastructures. What did we do differently here? Are these open-sourced 'critically-made' material infrastructures responsible for decreased energy consumption and low emergy? How would the infrastructure perform supported by the community's energy savings? Would community participants save enough energy for both the installation operations and the common wellbeing? The following sections present a detailed recounting of the excavation and methodologies of critical making, reusing and remediating material and media infrastructures, simulations and final installation to understand the complexity of this project and its underlying energy infrastructure.

4.2 EXCAVATION

4.2.1 A BRIEF HISTORY OF THE ELECTRIC METER

Although, the first long-distance transmission of electric current was realized by Marcel Deprez for the International Electricity Exhibition held at Munich in 1882, electric current in the 1890s in Europe and in America, was still a luxury, as there were no electrical networks yet. Theaters, department stores, factories generated their own current and most power consumed was for propelling electric streetcars.[14] But already by the 1920s the small intercity lighting systems of the 1880s had evolved into massive regional power systems - this momentum can be attributed to innovation, engineering pioneers, education and the requirements of war. Thus the years between 1880 and 1930s are the formative years of the history of the electric supply systems.[15]

Fig. 4.4. *Top*, Electrification in progress. Rural Electrification Administration (REA) erects telephone lines in rural areas. Photograph courtesy of National Archives and Records Administration; *bottom*, Rural electrification in the U.S. Original caption: "This collection of electric meters, receiving a final adjustment, is ready to be installed in U.S. farms where electric light and power have been secured through farmers' cooperative groups. These meters tell how much electricity is consumed each month. Each farmer's cooperative group, operating on a non-profit basis, tries to provide low cost electric service to its members. Such is the trust that the cooperatives have in their members that the members usually read their own meters and sometimes compute their own bills."[16] Photograph courtesy of Library of Congress.

In Networks of Power, Thomas Parkes Hughes says that this transformation and change in configuration was due to many fields of human activity, including the technical, the scientific, the economic, the political and the organizational….and this is because "power systems are cultural artifacts."[17] According to Hughes, "electric power systems embody the physical, intellectual and symbolic resources of the society that constructs them. Therefore to understand electricity and energy use one has to also understand the resources, traditions, politics, climate and economic practices of any given society. In a sense, electric power systems, like so much other technologies, are both causes and effects of social change."[18]

The embodiment of electrification in the form of the electricity meter (including the complexity of measurement and display of supplied electricity) is clearly seen in the history of its evolution. The electricity meters at the earliest were the remediation of gas meters. From chemical means of measurement to mechanical cylinders and gears for displaying data, from weighing copper strips to magnetic bearings, they have evolved today into much smarter visual machines. But, for the reasons of market economics they remain as such technological blackboxes, incomprehensible, abstract and concealed.

Samuel Gardiner's lamphour meter patented in 1872 was the earliest. It measured the time during which energy was supplied to the load. Here, the lamps connected to the meter were controlled by a single switch. However, Thomas Alva Edison proposed that electricity must be sold the way gas was sold and his "Electric meter" patented in 1881 used the electrochemical effect of current.[19] The apparatus contained an electrolytic cell, into which an accurately weighed strip of copper was placed at the start of the billing period. The current that flowed through the electrolyte caused a deposition of copper. The copper strip was weighed again at the end of the billing period, and the difference represented the amount of electricity used. Edison's meter was calibrated by which the bills could be presented in cubic feet of gas. These meters were used all the way to the end of the 19th century although meter reading was difficult for the utility and impossible for the customer. To solve this, Edison later added a counting mechanism to aid meter reading.

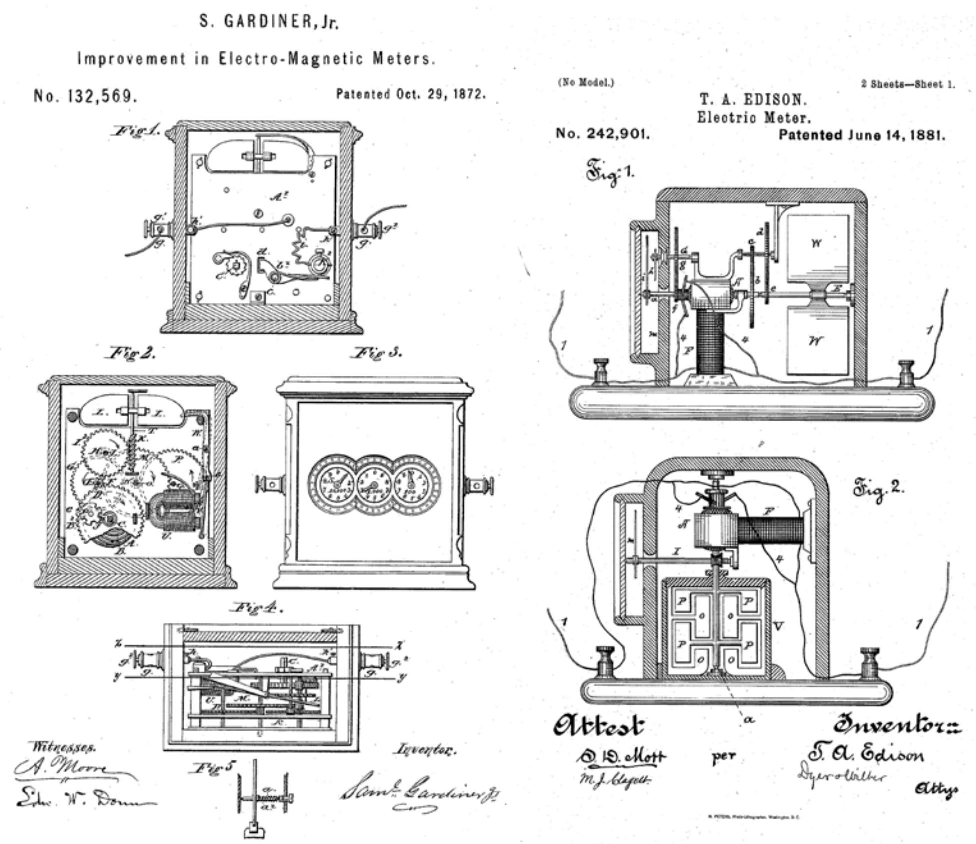


Fig. 4.5. *Left*, Samuel Gardiner's patent US132569 A. (1872). The inventor states that the meter apart from the general measurement of supplied electric current, it had the possibility to be also used for telegraphy, Public Domain; *right*, Thomas Alva Edison's Electric Meter Patent 1882.

Then, there were other electrolytic meters, for example the Siemens-Shuckert hydrogen meter and the Schott & Gen. Jena mercury meter. Electrolytic meters were able to measure merely ampere-hours and were not suitable when the voltage fluctuated. In the early decades of electricity distribution, it was not yet decided by the state or corporations whether direct current systems or alternating current systems would be more advantageous.[20] A significant disadvantage of direct current systems however soon became apparent that the voltage could not be controlled, and therefore it was not feasible to build larger systems.

Elihu Thomson's electricity meter in the 1890s was a small electric motor, where the speed of rotation of the armature was proportional to the power supplied. Here, the total number of revolutions of the armature that were automatically counted measured the total energy.

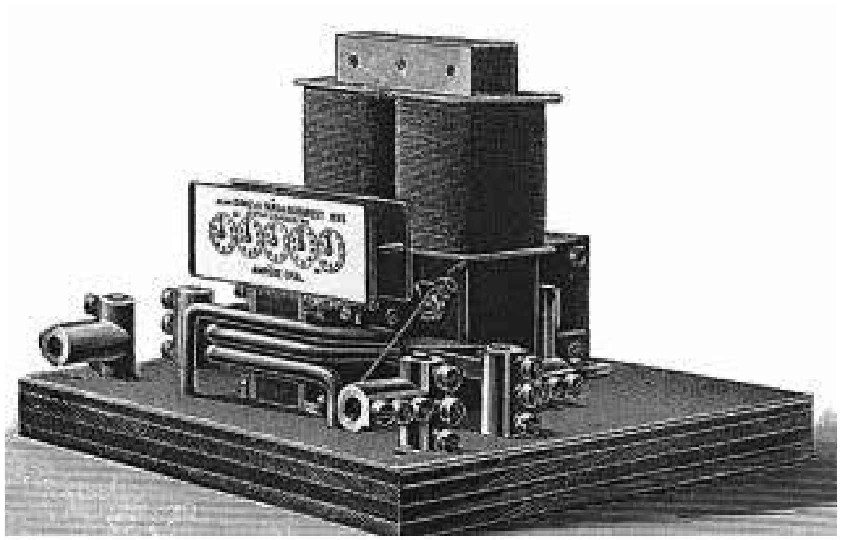


Fig. 4.6. Blathy's wattmeter in 1889. Public Domain.

In 1889, Otto Titusz Bláthy patented his 'Electric meter for alternating currents', that consisted of a metallic rotating body (a disk or cylinder), that was acted upon by two magnetic fields displaced in phase from one another. These first meters were mounted on a wooden base, running at 240 revolutions per minute, and weighed 23 kg.

Much improvements were achieved in the following years: reduction of weight and dimensions, extension of range of load, compensating changes in power factor, temperature and voltage, elimination of friction by replacing pivot bearings by ball bearings and then by double jewel bearings and magnetic bearings. Improvements also took on the form of long term stability by improved brake magnets and eliminating oil from the bearing and the register. By the turn of the century, three-phase induction meters were developed utilizing two and sometimes three measuring systems, all arranged on metallic disks. These induction meters or Ferraris meters were based on the principles of the Blathy meter. These are still manufactured in large quantities and deployed in many parts of the world.

Fig. 4.7. A typical smart meter, used by EVB Energie AG. It uses two way communication to reduce load, and connect/reconnect remotely, and also interfaces for gas and water supply. Photograph by EVB Energie, distributed under a CC BY-SA 3.0 license.

In 1972, Theodore Paraskevakos while working for Boeing developed a sensor monitoring system which utilized digital transmission for security, fire and medical alarm systems and for meter reading capabilities for utilities. This technology was a spin-off of another related patent: the automatic telephone line identification system or Caller ID. "The system used telephone lines (pre-internet) by which the device automatically generated electrical pulses for accessing a predetermined remote telephone receiver in response to the triggering of a connected sensor such as meter."[21] The system utilized the IBM series I mini-computer. This patent can be considered as the first iteration of a smart meter, becoming part of the early research development of Advanced Meter Reading(AMR) systems which later evolved into the Advanced Meter Infrastructuring (AMI) systems or Smart Grid.

By definition today, – "a smart meter is an electricity meter that by means of ICT communicates electricity usage to different channels such as in-house appliances, or external service providers."[22] It provides detailed information on electricity usage for peak consumption, averages, etc. It differs from a traditional meter by only displaying the current usage. The meter can also communicate the usage details directly to other parties, such as distribution system operators (DSO's) or utilities.

According to Hughes, historically, the methods of calculating cost of energy use is complex, a mix of load factor and economics, is deeply entrenched in the institutional monopolies that build the infrastructure.[23] By tracing the brief history of the electric meter, we found that measuring electricity has been a complex and industry-driven endeavor that took almost a century to reach today's levels of sophistication. From chemical methods to mechanical means for displaying data to electrical pulses and digital interface, electricity meters have been on the move. They have been patented, developed by various inventors and energy providers to provide accurate numbers of consumption to guide the recovery of investments in electrical infrastructures. These patents, commercial interests, and general ubiquity of electrification today perhaps could be the reasons why electric meters remain as such technological blackboxes, incomprehensible, abstract and concealed.

4.2.2 ENERGY AND NORDIC MATERIAL CULTURE

We discovered through our research, that the electrical meter (usually the property of the energy provider) is not visibly located anywhere near the individual's home, rather in the cellar of the buildings. This is an obstacle for individuals and families to track their own energy use placed outside the sphere of their daily lives. Electricity is regulated by local energy provider that decides its production, cost and distribution. Therefore, it is not easy to comprehend the daily consumption of electricity. According to Marttila et al., "a 'fact' of consumption through its billing procedure gets converted to scalar quantities like units or kilo watt hours, and reaches its metering address often in numbers, or then gets invisibly incorporated as cost within products, services and spaces."[24]

Fig. 4.8. Smart Meters locked up inside a central electricity room in the basement of an apartment building in Rihimäki, Finland.

Smart metering that is set to be introduced into European and Nordic homes in the next few years has also been met with opposition from the EDPS (European Data Protection Supervisor). It said the technology could be used to track what "households do within the privacy of their own homes, whether they are away on holiday or at work, if someone uses a specific medical device or a baby monitor, or how they spend their free time."[25] The EDPS also claims that the vast amount of information collected by the new generation of devices could have serious consequences for consumers and what they pay for their energy, combined with the potential for extensive data mining." As such, personal or family energy data has become a privacy issue and something that cannot be openly published or shared with the community. The same goes for domestic energy objects that are never analyzed and considered in context of the general public wellbeing.

In the North Temperate Zone where the temperatures are below freezing for a period of many months, lighting and heating are important supporting factors in the general lifestyle of the people. They can be considered significant reasons relating to wellbeing in the Nordic countries.

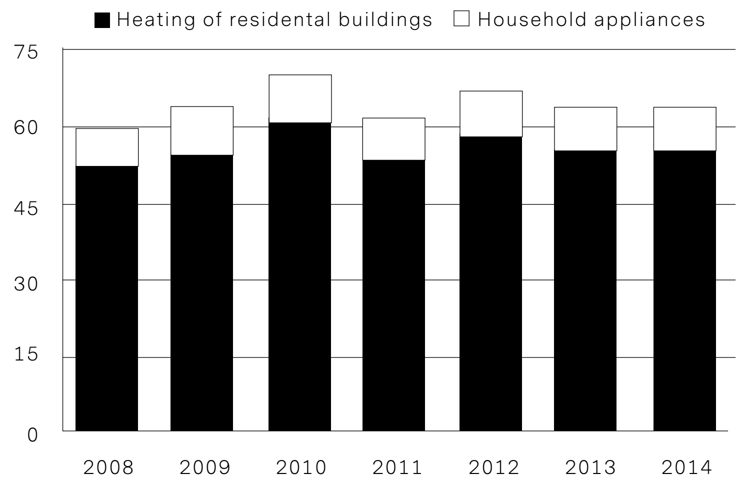


Fig. 4.9. Energy consumption in Finnish households in 2008 to 2014. Energy consumption in households, that is, heating of residential buildings and household appliances amounted to 64 terawatt hours (TWh) in 2014. Official Statistics of Finland (OSF).[26]

These twin factors of heat and light are energy intensive and lead to the use of energy intensive electrical appliances and related consumer products. In a way, the use of energy can be said to support people's wellbeing that also results in the production of energy using processes and artifacts. Such artifacts can be regarded as heritage since they have been inherited from past energy-using generations in a continuously evolving form, still maintained and used in the present and likely in the future.[27] Embedded with stories and narratives these are significant elements in the daily lives of the Nordic people, thus may be considered as part of contemporary Nordic material heritage and as a manifestation of energy use in the Scandinavian region.

"Since the basic notion of material culture emphasizes how apparently inanimate things within the environment act on people, and are acted upon by people,"[28] it becomes crucial to examine the relationships between material culture and society. This dimension resulting from high levels of consumption of energy in various communities is an issue that is today significant to the ongoing global energy debate and the long-term effects on the environment.

In our energy intensive societies, we are not only shaping our nature, ecologies and environment but are also engaged in the act of producing energy appliances and artifacts.[29] Some of these artifacts today, as part of the material culture of communities are obsolete, a few in use, and others with nostalgic value. Each have their own personal narratives by their owners, each one their own histories. They have transformed from mere electrical appliances, radios, light fixtures to energy artifacts of society's material heritage. This resulting heritage and energy use are both symbolic and empirical representations of the energy intensive lifestyle of communities and are socially relevant issues.

INITIAL ENERGY MAPPING 4.2.3

We initiated the design intervention in the community neighborhood of Kallio in Helsinki. Kallio is a diverse, experimental and cultural area of the city. Being also a high-density neighborhood, with a vast number of apartment buildings and residents, and thus energy-use, we thought this to be an ideal site to initiate a dialogue in the public context.

Our energy mapping exercises began with interviews with the 16 participants from the chosen neighborhood.[30] We examined the

As part of a community art project are you willing to share your home electricity reading with us for one week, just once everyday?

YES	10	83%
NO	2	17%

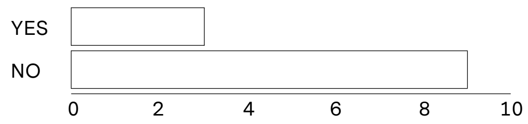
People may select more than one checkbox, so percentages may add up to more than 100%

Fig. 4.10. Question 1 from initial survey asking community members to share their energy meter readings.

residential spaces of the community and the related energy use. This energy intensive lifestyle is led mostly indoors and occurs inside the individual private space of the community members. This space is usually the living quarters of a person, the bedroom, a studio space or even a personal sauna. An abundance of lighting fixtures, electrical appliances are visible in these private spaces that not only contribute to wellbeing but also involves substantial energy use. This process enabled us to understand and analyze their energy footprints and self-reflection that went into the publishing of their personal energy data. The responses from the initial online survey served as the basis to conduct these interviews (see Appendix). Our survey asked questions relating to the willingness of the participants to volunteer and donate an electrical artifact for public exhibition. We also asked them whether they were willing to share a domestic energy artifact, publish and save their electrical energy use on a daily basis.

The interviews conducted over a period of two weeks documented the participants' living spaces in context of energy use, the energy artifacts they used, and the associated wellbeing. Some were conducted at the participant's home and some at the University. Participants were informed of the mechanics and operations of the project, the online process of reporting energy data from the power company's online portal, and publishing the data through our specially designed web application. An instruction sheet was provided to every participant as guidelines (see appendix 4.1). We applied multi-modal methods such as sketching, writing, talking, photographs etc. during the interviews.

Do you have your electricity meter located within your apartment that you can see everyday?



YES	3	25%
NO	9	75%

People may select more than one checkbox, so percentages may add up to more than 100%

Fig. 4.11. Question 4 from initial survey asking community members to locate their electric meter.

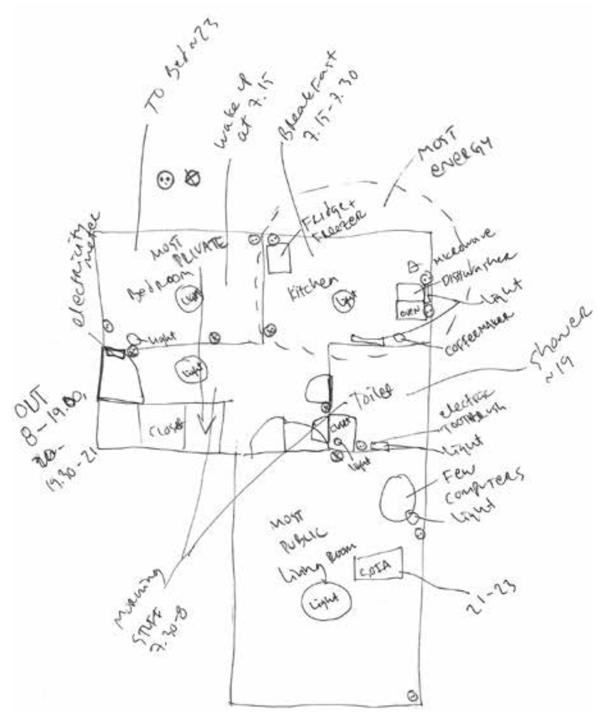


Fig. 4.12. Energy mapping of a participant's home.

Through this, we sought to encourage interviewees to become engaged with our processes.

Energy use was documented through layout sketches that marked spaces that the participants considered to be of high energy and low energy consumption. Figure 4.17 depicts a participating couple's sketch of their apartment's layout and log of energy use. At first, the participants were asked to sketch their homes on paper indicating the various private spaces of their homes. Then they were asked to indicate the various appliances, light fixtures and electrical artifacts located around those spaces. We talked and discussed during the interviews about their daily lives and activities around the use of energy and energy artifacts in their homes. This was then charted onto the layout plan of their homes for an entire twenty-four hour cycle from waking up in the morning to going to bed. Here, the participants had to map what spaces and electrical objects according to them were of both high and low energy use. We analyzed the homes and electrical artifact use in domestic space from the group of participants. This format of recording was continued for all the 16 participants. These interviews provided us the framework of the installation by allowing us to explore the private energy lives and artifacts of the community participants and configuring a process to exhibit their contemporary energy-use.

Thus, related to private-public space and community, our installation meant to question whether community participation, open publishing of private energy data and display of private energy artifacts could lead to awareness and wellbeing? We also questioned whether people would be willing to negotiate their energy use in their private space of their homes to brighten therapy lights in the public space for the well being of the passers-by?

4.3 OPERATIVE METHODOLOGIES

These are the methodologies that emerged during the design, construction and deployment of the project. The principles of Constructive Design Research was considered initially in this design intervention. However, the dominant methodology could be seen as Critical Making besides other significant methods such as Tactical Reuse, Circuit Bending, Remediation, Self-publishing, and Open Source. Microstructuring by itself was a methodology used in the planning and deploying of the project. In the broader scope, the project plays within a historical framework of nordic material culture and energy use and therefore presents a remediated history of the present through repurposing of old media.

TACTICAL REUSE 4.3.1

According to Hertz:

> *Reuse is focused on challenging institutional structures through the tactical repurposing of media technologies. Tactical reuse can be seen as borrowing from the concept of détournement, a technique of appropriation outlined by the Situationists in the 1950s. In détournement, well-known objects and images are used and taken through a detour to create an alternate message, often in oppositional contrast to the original source. Here, situationist detournement, tactical media and critical design are borrowed on to construct a type of reuse that is used to directly clash with social and institutional conventions, often targeting themes of social injustice, globalization, consumer culture, or the environment.*[31]

Reuse in Light is History was aimed to challenge the material and media infrastructure of the museum. In our project the obsolete electric meter as a media artifact was reused and repurposed into lamp and artifact display modules. This mimicked the methods of presentation by museums (as vitrines) and the material infrastructure that supports the exhibition of artifacts in a museum.

Reuse in our project was a significant part of the making process. The Trashlab forum provided us with a local community of artists, designers, hackers, makers, re/up-cyclers and activists working with material and electronic waste. With feedback and assistance from this

Fig. 4.13. Sorting through a dumpster filled with obsolete electric meters. Photograph by Karthikeya Acharya.

community we developed our project into a case example of making, reuse and remediation (for details about community participation, see 4.5.3.).

4.3.2 CRITICAL MAKING

According to Hertz:

> *"doing something yourself, as a non-expert, is a crash course in understanding how something actually works, and it is the fastest way to unpack and learn about the things that would normally remain invisible and taken for granted….. that the process of being humiliated by things that you think are easy or mindless is a valuable experience - innovation out of porting your ideas and processes into a field that you're not familiar and actually doing this on a regular basis is a crucial plan of practicing inventiveness."*[32]

Making without reflection and material goals can often lead to material waste and energy use. Given the cheaply available tools of rapid prototyping and fabrication, one is tempted to tinker and make endless iterations without sparing a thought about the embodied energy of materials and the corresponding energy use of shaping them. We have frequently wondered how to strike a balance between making and purpose, making and reflection, and making and materiality. How could hands-on 'making' supplement and extend critical reflection on technology and society? As Hertz says, "the method of Critical Making works to blend and extend the fields of design, contemporary art, DIY/craft and technological development and it also can be thought of as an appeal to the electronic DIY maker movement to be critically engaged with culture, history and society.[33]

As already mentioned in 2.8 about Critical Making, Ratto says that:

Critical Making is a mode of materially productive engagement that is intended to bridge the gap between creative physical and conceptual exploration: an intention to theoretically and pragmatically connect two modes of engagement with the world that are often held separate—critical thinking, typically understood as conceptually and linguistically based, and physical 'making, goal-based material work…..[accordingly] the creation of one's own tools permits critical analysis of the designs and constraints involved in the research, and thus avoids technologically-deterministic experimentation and directly confronts issues of pragmatism and theory.[34]

This research considers Critical Making as an approach that simultaneously combines critical discussion with hands-on making and analysis. Our project had a preplanned process of making with a critical disposition rather than a spontaneous cranking of the prototyping machine. We delved into literature, concepts and theories before our attempt at sketching a prototype. We jointly designed and built the initial modular units and the final installation. We focused on 'learning by doing' in a collaborative team. Through the making process, we gained knowledge of electric meters, their components, their actions. Our work also overlapped traditional fields of wood working, electricity distribution and emerging digital technologies. Thus, our project

Fig. 4.14. *Top,* Dismantling the obsolete electric meters in the lab; *bottom*, Hands-on construction of the modules in the lab.

was realized in a multi-disciplinary approach, reused electronic waste, open source hardware, and readily available components. Our project had its "emphasis on critique and expression rather than technical sophistication and function."

CIRCUIT BENDING 4.3.3

Circuit bending is an electronic DIY movement undertaken by individuals without formal training or approval and focused on manipulating circuits and changing the taken-for-granted function of the technol-

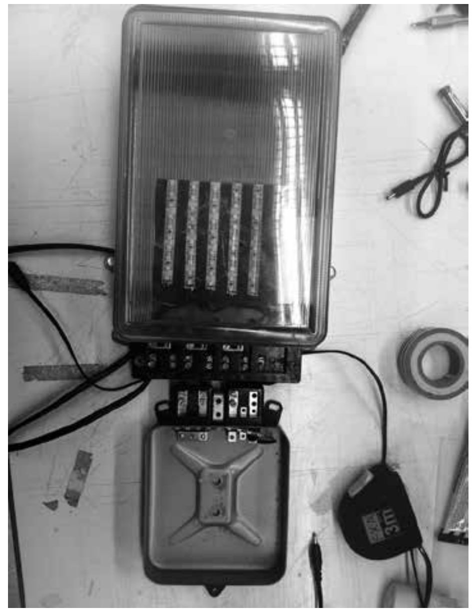


Fig. 4.15. Rewiring two obsolete electric meters together.

ogy. Thus, "the manipulator of consumer electronics often traverses through the hidden content inside of a technological system for the joy of entering its concealed under-layer, often breaking apart and reverse-engineering the device without formal expertise, manuals or defined endpoint."[35]

Our design intervention was preceded by the breaking of technological black boxes and rethinking them in a new light. In Light is History, we broke into a classic technological black box: the electricity meter. We repurposed the black-boxed meters in the project, transforming them into novel open media artifacts with new operations and processes. The transformed electric meters were thus resurrected "to new uses, contexts and adaptations."[36]

4.3.4 COUNTER-REMEDIATION

In what we call 'Counter-Remediation', the old media remediates the new into an unfamiliar outcome, where both are transformed and exist simultaneously thereby generating new critical understandings. Here, hypermediacy is used to display the incongruities between media in order to frustrate immersion and fosters critical awareness. [37]

In our design intervention, a Lamp and Artifact Display (LAD) module consisting of the lamp and vitrine remediate the older artifact (the electric meter) by refashioning it and re-introducing new goals and functionalities. The visual outcome is unfamiliar where both media exist in a state of hypermediacy.

The modules are also embedded onto a new compositional interface on a tangible surface made from recycled wood. Thus the repurposed electric meters are set apart from their original visual orientation and angle of view. These discontinuities between the obsolete artifact and the new artifact combines a double remediation where the original and the new exist in a state of multiple meanings.[38]

Counter-Remediation also happened when the electric meters of the installation by their very shape and form remediated the algorithmic programming of the lamps by framing the Lux and Lumens output. Thus even the novel light intensities were moulded by the form of the old media, in effect forcing the algorithm to conform to new physical realities.

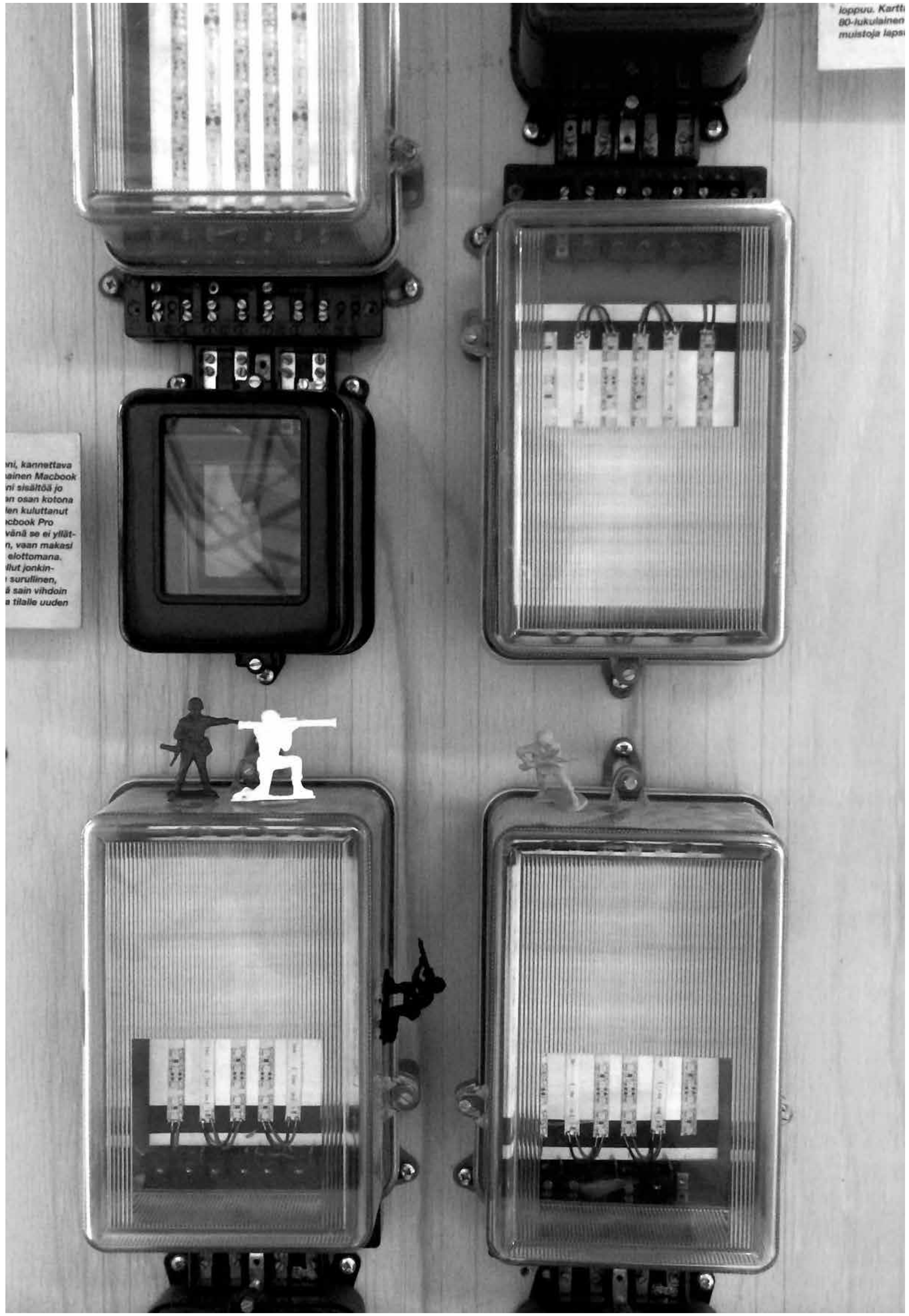


Fig. 4.16. The obsolete meters now remediated into lamps and vitrines.

4.3.5 SELF-PUBLISHING

Self-publishing could be regarded as a DIY method. For example, when punk music emerged in the 1970s, self-published zines were quickly embraced as part of the DIY culture. "The significant avenue for DIY intervention in music was self-publishing, particularly with "zines"—independently created publications, usually handcrafted and photocopied incorporating the two elements of dis-alienation and anti-establishment."[39] Although, self-publishing today has evolved into a giant phenomena in the publishing industry especially assisted by online media giants, in our project it was used as a tool and method to circumvent traditional gatekeepers of energy production and distribution, i.e. the local energy provider in Helsinki.

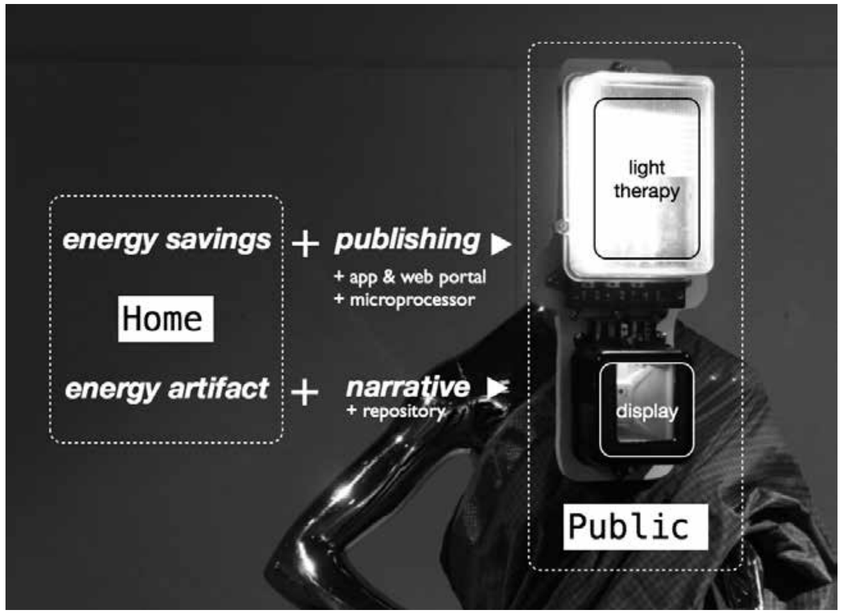


Fig. 4.17. System diagram showing the self-publishing methods.

In Light is History, self-publishing was used as method by the participants to generate digital and material content for the installation, the energy application and the digital archive. Through self-publishing their own energy use through our specially designed web application, the participants bypassed the control of the local energy company who refused to provide us access to their database. The energy savings data from the participants were processed by the onsite microprocessor to generate variable light intensities, as a visualization of their domestic energy consumption. This daily self-publishing of energy data was crucial to the operations of the installation and the resulting public awareness and wellbeing. The act of self-publishing was also expanded to curating domestic energy artifacts of the participants and the associated personal micro-narratives. These were published and embedded on the installation via traditional print media and on the archive as a digital repository of images and text.

Daily self-publishing by the participants (as collated in the feedbacks) put the onus on the participants as a stakeholder, as in a DIY attitude of anti-establishment. It also helped to raise the notions of responsible consumption behaviors and during the installation even encouraged them to change attitudes towards energy savings. Beyond a daily task, according to a participant, "it became an addictive game to track their own energy footprints and effects on the installation."

OPEN SOURCE 4.3.6

Open source software and hardware allowed us to inexpensively build our design while collaborating with others. The primary Open Source aspects in this project were the Arduino microcontroller software and hardware embedded in the installation. The Arduino microcontroller has a single integrated circuit containing a processor, memory and programmable input/output peripherals. It can be used to build small-scale digital devices and interactive artifacts. The board designs are available under a Creative commons Attribution Share-Alike 2.5. License. The software, the Arduino IDE(integrated environment development) is a cross-platform application, developed collaboratively.40

Vast repositories of codes, designs and hacks are freely available along with support, collaboration and discussion forums.

Our project was conceived as an Open Source project. Thus the design can be branched off to a new direction and re-implemented by others. The physical installation in itself is available to all who are interested to reuse and repurpose it. The programming codes and design drawings are openly available.

4.3.7 MICROSTRUCTURING

The material and media infrastructures of Light is History were micro-scaled to present microhistories of energy artifacts. This microscaling of infrastructure happened in four domains: 1. Vitrines; 2. Personal narratives; 3. Digital Archive and 4. Web application. Microstructuring also aided in the project management and the scale of engagement with participants.

The 20 vitrines (artifact displays) were no bigger than 15 cm by 12 cm in dimensions. Ten of these were all-around clear see-through glass cases while the rest had merely a 6 cm by 6 cm rectangular vertical window surrounded by a metal frame. The small size of the vitrines influenced the size and format of the artifacts. The participants identified common energy artifacts within their domestic spaces that were far too large to be accommodated within the small enclosure of the vitrines. Thus, after much reflection we situated the artifacts inside the vitrines as small printed photographic media. This decision to scale down the tangible artifacts of the participants into photographic documentaries widened our options for curation. We were no longer limited by the size of the artifacts or the vitrines. And, at a microlevel the small images of large electrical artifacts in old wooden frames transformed them into memorialized objects.

The size of the participant narratives were also limited to a paragraph, 200 – 300 characters, approximately on an average 50 words. The recycled metallic labels that were attached next to the vitrines were designed to be not more than 10 cm by 10 cm. The typography

Fig. 4.18. The participant narratives attached to recycled steel plates.

was restricted to Helvetica Bold, font size:14 and color: black. The narratives were printed on clear acrylic sheets that were then glued onto the metallic plates. The amount of textual information beside each vitrine was thus restricted within a square window, quite proportional to the dimensions of the vitrines themselves. These along with the lamps became part of the micro-scaled public identity of the participant in the market square.

We fashioned the digital archive as a tool to share small packets of content (micro-posts) serially and easily. Not only it housed the artifacts of the participants online, it also allowed following, re-blogging and building linkages through the micro-posts. The archive has a simple uncluttered back-end user interface from which one can manage and maintain multiple artifacts and archives.

Microstructuring also happened in the interface design and coding of the web application. The user interface is compact and minimal and mobile responsive, or "an optimal viewing and interaction experience which makes for easy reading and navigation with a minimum effort of resizing, panning, and scrolling across a wide range of devices from desktop computer monitors to mobile phones."[41] Our web application collected electricity meter readings of the community participants on a daily basis during the installation. The HTML and CSS code is also kept to a bare minimum without too much decoration and embellishment.

Microstructuring the project (as opposed to infrastructuring) assisted and benefitted our project on several fronts. Being a small team of two researchers, we had to streamline the project management to deploy the project on time. This involved efficiently organizing communications, design research, curating, digital asset management, programming, making (building) and logistics on a tight time schedule. These tasks are quite similar to what a museum undertakes in its daily workings. We had to scale down work related to guidelines for participation, benchmarks for artifacts, lighting specifications and feedback processes. All of these had to be in a manageable scale and format for our small team.

The project had limited resources in terms of funding and materials. As such a considerable infrastructure of the project was recycled and reused. We worked out of a minimal budget most of which was assigned to the LED strip lighting (no recycling available), transportation and hardware. Despite that, we were able to construct quickly and efficiently deploy the mainframe installation due to the microscaled modular nature of our design.

Finally, microstructuring the project provided a clarity of engagement to us and the participants. There were clearly defined microtasks, designs, codes, interfaces and vitrines for all stakeholders. This clarity of process we think is essential to Critical Making with community.

HARD MEDIA INFRASTRUCTURE 4.4

ELECTRICITY METERS 4.4.1

The 'Critical Making' of our open system ironically involved breaking into a classic technological black box: the electricity meter. For over a century, this media artifact has been providing measurements of electric energy consumption typically calibrated in the form of kilo watt hours and displayed on its interface in numerals. Its internal technologies and workings are hidden from public view and usually they are owned, sealed and tamper proofed by the energy companies (electronic technologies did not find their way to metering until the first analogue and digital integrated circuits became available in the 1970s). As such, third party innovation or development has not been possible for a long time in analog electricity meters. Thus the electricity meter that measures one of the most crucial aspect of our lives, i.e. energy consumption, is normally not easily comprehended by people. This has also led to indifference to energy us.[42] In this context, the decision to reuse electricity meters as a display system for the project was intended to revive an old interface in a novel way. The meters served as alternative media artifacts for the visualization of energy consumption and human behavior in the form of light, artifacts and narratives. In a way the meters that were pronounced obsolete took on alternative "zombie" forms resurrected into new uses, contexts and adaptations.[43]

Thus, our display system was repurposed from discarded analog (electro-mechanical induction watt-hour) electricity meters made by Valmet Corporation of Finland. Around 40 meters were recovered from the waste dumpsters of the metering company of the local energy provider.[44] The meters salvaged were from three different commercial and residential types: 1. Orange metal back casing manufactured in 1985, 2. Black metal back casing manufactured in 1986, both with full plexiglass enclosure and the third older one was from 1963 with a full metal casing and a smaller glass window. They were all kilo-watt-hour meters, measuring AC (alternating current) 220 Volts, 50 Hz.

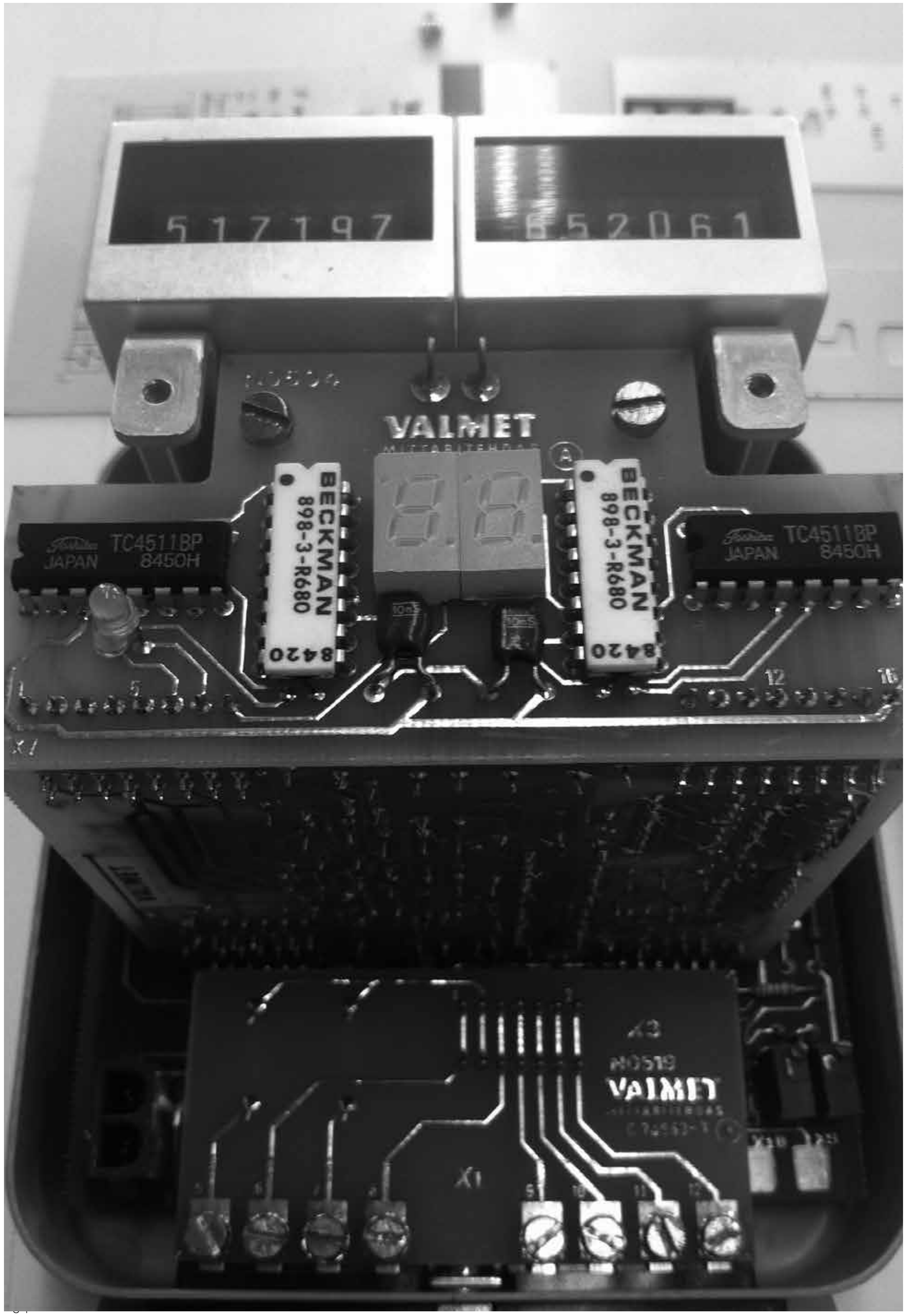


Fig. 4.19. An Electric meter stripped of its outer casing.

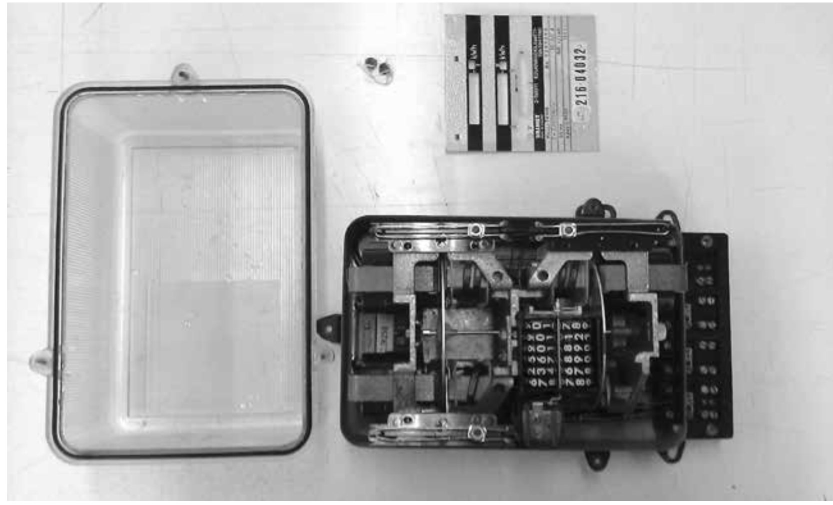


Fig. 4.20. The innards of the electric meter.

The meters were emptied of their mechanical and electrical contents in the lab over a period of two weeks. What emerged from the black box was a history of mechanical engineering since the twentieth century: a wide assortment of metal parts, coils, wheel-and-disk mechanisms (integrators), copper conductors wrapped around magnets (transformers), circuits, gears, shafts, etc. The main visual component being the spinning wheel run by a system of gears that operated a multi-digit display very similar to an automobile speedometer. Most of these parts were obsolete in context of the project, thus could not be reused. Once emptied and cleaned, the electricity meters were transformed into glass and metal boxes, the alternative vitrines for embedding the lights and placing the artifacts.

LAMPS & VITRINES 4.4.2

Initially, we investigated into another black box (in this case, a light box) hardware sold as commercial therapy lamps to understand how they work. This was in response to the challenge of energy use and related Nordic material culture as discussed in 4.2. The bright light therapy box was a ubiquitous object in Finnish households just like the electric meter, and itself was a blackbox.[45] We explored various options related to the design and construction of therapy lamps. What was the light intensity needed to simulate the bright light therapy? What were the scientific theories behind such products? Would our simulation be close enough to approximate the 10,000 lux needed?

We discovered that although the pathophysiology of Seasonal Affective Disorder (SAD) remains uncertain, studies of bright white light-induced melatonin suppression in humans led directly to showing that light could be used therapeutically to treat winter depression,[46] and phase shift circadian rhythms.[47] Yet, the field of light therapy is peppered with manufacturers, scientific papers for and against, conflicting debates about how much light is needed to effectively fight against SAD. No single resolution of light therapy has been accepted as appropriate. Much of the technology remains hidden under patents and disclaimers. As such, our project instead of indulging in scientific demonstration attempted to be a simple pilot illustration of the principle and thus approximate the light intensities of bright light therapy lamps.

Fig. 4.21. A LED strip. Photograph by Karthikeya Acharya.

Light Emitting Diodes release energy in the form of photons, the effect is called Electro-luminescense (electrical phenomenon in which a material emits light in response to the passage of an electric current). The earliest LEDs emitted low intensity infra-red light and were commonly used as transmitting elements in remote-control circuits for consumer electronics such as televisions and video cassette recorders. Recent technological breakthroughs have allowed the LED to consume less energy, longer life cycles, smaller sizes and faster switching than normal incandescent light sources. Although the cost remains a prohibiting factor, LEDs are now widely used in DIY and hacking projects around the world. In our project the LED allowed smaller packets of energy savings to be translated into lights and we could assemble and build the lamps in a small container space of the electricity meters.

Fig. 4.22. Lamp and Artifact Display (LAD) module.

Our lamp & artifact module consisted of an integrated set of 2 emptied electricity meters. Emptied commercial meters were assigned to the therapy lamp and the smaller residential meters were reserved for the artifact collection. 20 such modules were assembled comprising of a total of 40 light sources. The light units designed and built to simulate our therapy lamps consisted of an array of 6 LED (Light Emitting Diodes) strips, each 15 cm long made up of a total of 108 LEDs. These were mounted on a black non-conducting plate on the inside back surface of the meter, and connected in series. A single 7.5 cm strip consisting of 9 LEDs was installed on the top surface of the smaller meter for the artifact display.

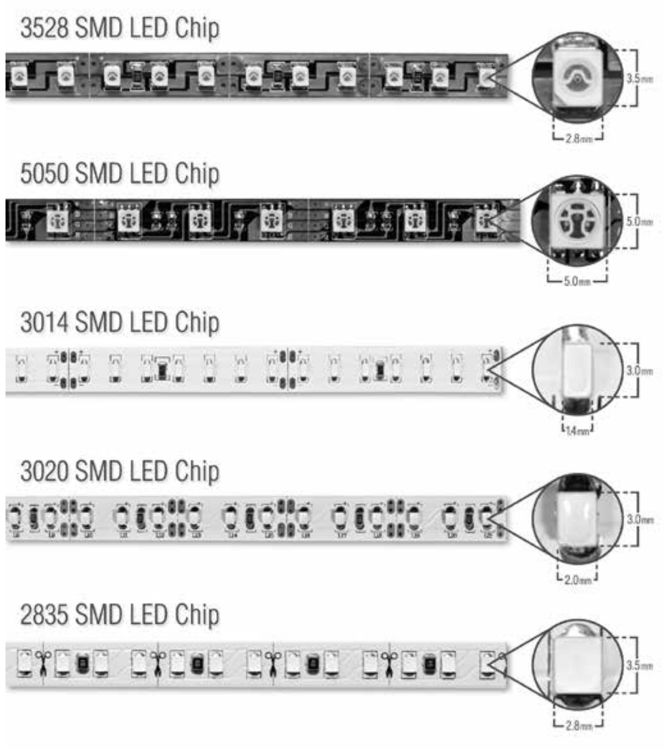


Fig.4.23. Comparison of SMD LED Modules on strip lights.[48] Image by Brent Mauriello, distributed under a CC BY-SA 4.0 license.

The therapy lamp was controlled for its intensity based on user input (the energy usage of one participating family in a day through a state of brightness.) received by a database on the project server (This simulated the 10 000 Lux of light used in commercial light boxes), whereas the light intensity of the artifact display remained in a constant state. Together they provided a light intensity reciprocal to the energy savings of the participants during the installation phase of the project. Our array of 100 LEDs had an output of approximately 1000 lumens per lamp. We did not scientifically measure the on-site light intensities, however we charted the spread. The Illuminance or Lux as a measurement of the light intensity at any point was approximately 10 000 lux standing close to the installation, thus simulating commercial therapy lamps. The light intensity dropped exponentially the further away one was away from the installation.

MICROCONTROLLER 4.4.3

We needed moderate and inexpensive processing power that could compute the energy savings of the community sent from a web application and transmit that energy data onto our light sources. The hardware we chose to build this functionality was the Arduino microcontroller made by Arduino, an open source hardware and software company. The microcontroller itself is not a full-scale computer, but a smaller one with a single integrated circuit containing a processor, memory and programmable input/output peripherals. It can be used to build small-scale digital devices and interactive artifacts. The board designs are available under a Creative commons Attribution Share-Alike 2.5. License. The software, the Arduino IDE(integrated environment development) is a cross-platform application written in Java and can be easily worked upon by beginner-level programming skills. There are vast repositories of codes, designs and hacks freely available on the Internet along with support, collaboration and discussion forums. Arduino microcontrollers are extensively used especially in DIY and Hacker projects, interactive museum exhibits,[49] and as open source scientific hardware in research projects.[50] It allows makers the world over to create projects that are interfaced with a variety of sensors and actuators, glued together and orchestrated with software. For this generation of makers, hardware is no longer a black box.[51]

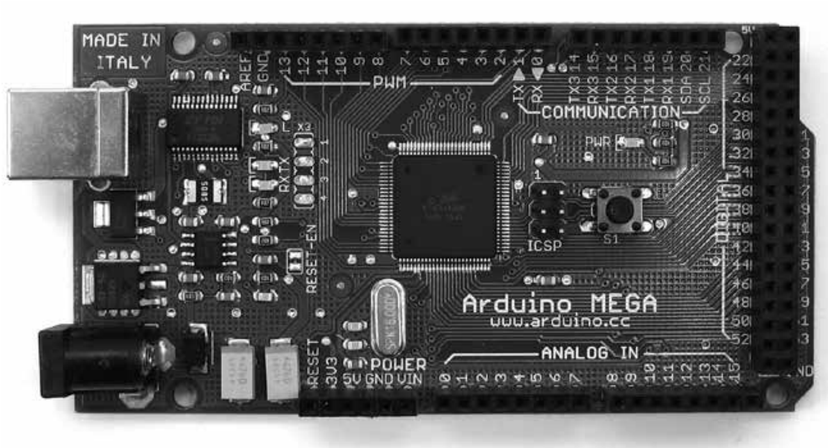


Fig. 4.24. Front side of an Arduino Mega board. Photograph by David Mellis, distributed under a CC BY 2.0 license.

For our project, we calculated the need for a single microcontroller to control all the 20 lamp and artifact display(LAD) modules. As such, we chose the Arduino Mega 2560 (Arduino 2015) for the project. It seemed to have the most I/O ports for adding the LADs. With 54 digital I/O and 16 A2D(Analog to Digital) inputs, there was plenty of room for any other sensor, servo, communications link, etc. Well built, easy to connect, and with a vast array of useful shields (plug in boards that add functionality), the Arduino circuit and processor is also rugged enough to withstand widely varying season temperatures (this was crucial since the installation was in place in late-November to early December). The Mega is also energy efficient and offered a clean IDE to program the lights (we will deal with coding under Media Infrastructures). It connects without lag and the sketch loading is fast. The built-in USB port was convenient for us to connect to an external computer. There are many interface options and multiple vendors are available to provide products. The board is expandable with any number of assorted pre-made shields or any custom circuit one can design. The 256k of flash program memory was more than enough to gather energy data of the participants and process them for the installation.

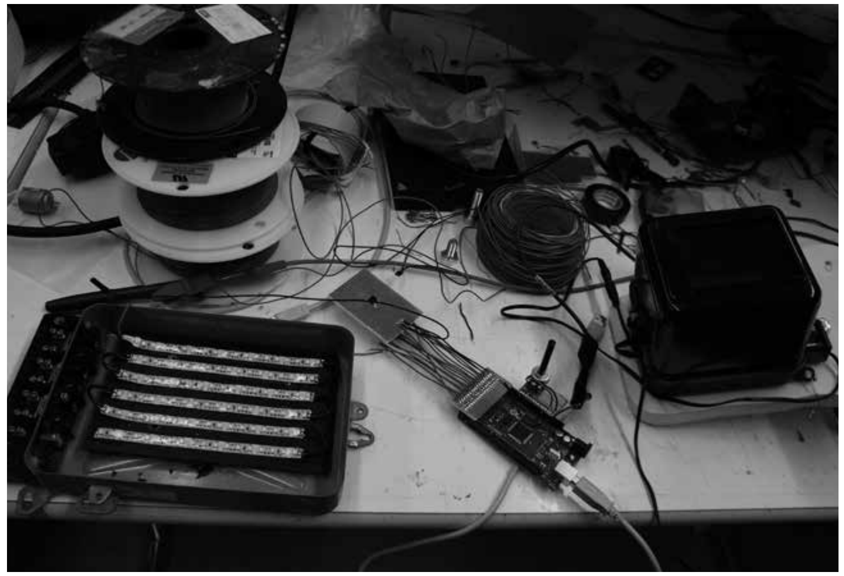


Fig. 4.25. The Arduino connected to the LED strips.

As an artistic tool in our project, the Arduino microcontroller conveyed data to the artwork(the physical installation) and in the end the tool itself got embedded within it. It played a key role in transmitting energy data in the form of numbers from the electricity meters of the participants to the LAD module in the form of a set of instructions that triggered varying degrees of illumination. Although the microcontroller itself was placed inside a box, waterproofed and hidden from view within the installation, its function and materiality became an inherent part of the installation. Not only did it connect different materialities of hardware such as the electricity meter and the installation but also connected various spaces, such as the private home of the participant(and the appliances within it) to the public square. Thus the Arduino in our project became a vital connection between material infrastructures of domestic spaces, consumer electronics and digital media, forming a link between the various disparate materialities.

4.4.4 URBAN INTERFACE

The mainframe infrastructure-the interface of our open system sited in the Hakaniemi Market Square was specially designed in the labs and assembled in wood and metal workshops. It was constructed from recycled and Forest Stewardship Council (FSC) certified plywood. The form of the mainframe was decided in the preliminary stages of site and community research. Studying the Market Square site raised several questions related to the appropriate form and dimensions of the mainframe. In what physical form could the installation positively affect the transitional pubic on the Market Square? What should be its height, width and depth based on the scale of the Square? How big should the mainframe be to make or not make a visual impact on the Square? What construction material would be suitable in the dark cold months of the Finnish autumn? How should the LAD modules be placed to form the interfaces of the installation?

Fig. 4.26. Siting the installation in Hakaniemi Market Square.

The Market Square as the physical site for the project allowed us to narrow down our design for the interface. First of all, the site was in close proximity (approximately a kilometer walking radius) to the participants from the Kallio neighborhood. The Square is a major transit center with trams, buses and metro connections. It is almost a hundred meters long by eighty meters wide and a busy open-air market for vegetables, fish products, flower shops, makeshift cafes, nurseries and other mobile vendors. It houses a market building at the northern end along with metro entrances and bus stops. This attracts thousands of daily local residents, visitors and commuters. Hakaniemi Market Square has also a significant place in the national history of Finland as a place of political resistance and as a place for public participation and gathering.[52] Thus, several potential locations were identified for installing the Mainframe that would have allowed higher visibility, participation and impact for the installation. However, one of the limiting factors was the availability of power supply boxes of the local energy provider Helsingin Energia. As such, we chose the location behind the entrance to the Metro Station and in front of the Hakaniemi Market Hall as the most appropriate for the project due to the crisscrossing of pedestrian traffic routes and the available power supply point (see figure 4.32).

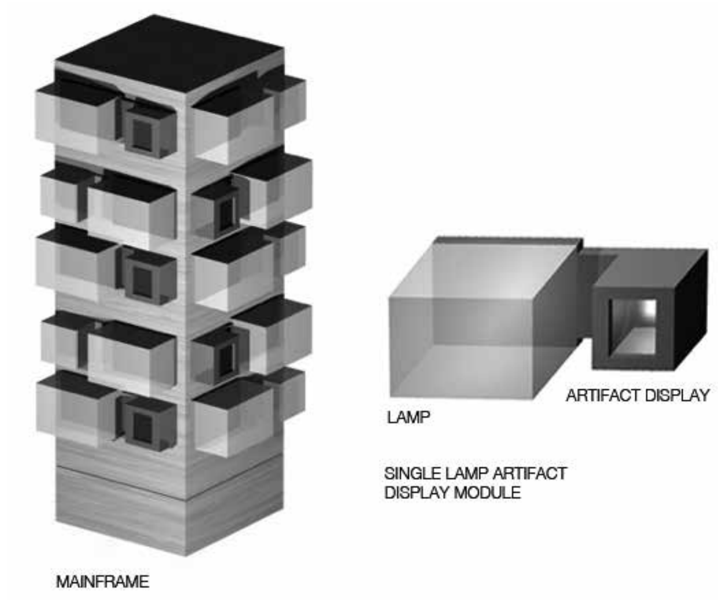


Fig. 4.27. 3D model of the mainframe and individual LAD module.

The interface design for the mainframe was decided by the dimensions of the 20 LAD modules (the total number of participants), the light intensities, the human eye-level, the visual clarity of the artifacts and their associated narratives. Based on this, several layouts for the modules were sketched out. We had to take into account the layout and size (figure) of each individual LAD module that consisted of two electricity meters placed opposite to each other, one larger(size) to mimic a therapy lamp or the Light Box (L box) and the other smaller(-size) to mimic a typical museum vitrine or the History box (H box). We decided upon a human-scaled orthogonal four-sided cubic mainframe on the square, as shown above in 4.33., i.e. 2 meters tall and 50 centimeters wide on all sides. Thus, each side was allotted 5 LAD modules or five participants facing the cardinal directions on the Market Square. We attempted to concentrate the modules around the human eye-level, so that the artifacts within were clearly visible and that the range of the light intensities of the therapy lamps reached the onlookers.

The design and construction process of the mainframe was reflective-in-action. We at first build the mainframe in the wood workshop and then started laying out the LAD modules. Every design move was enacted physically and defined interactively through the layout variations of the modules and the heights of their placements on the mainframe interface.[53] Whereupon the global interface and layouts kept changing until we reached a satisfactory point in the design solution. Even then, the complete interface was far from satisfying all the necessary variables. As such some module placements were accepted, others were marginally accepted and still others stayed on the fringe of being unnoticed and ineffective. This reflective design process and conversation allowed the project to develop the interface and improve it further.

Although the aesthetics of our infrastructure was not a priority in the installation, our goal was to convey the project to the public audience as an open and participatory museum installation. Here, the LAD modules were the primary visible objects, the main artifacts and the wooden mainframe acted as the ‘white-cube’ base. And, unlike museum galleries, our mainframe was not polished or painted but left

Fig. 4.28. *Top*, The plywood mainframe under construction at the University Wood Workshop; *bottom*, The mainframe in the electronics lab with lamps installed.

exposed with its natural wood grains visible. The screws and hinges were sourced from basic home-construction hardware. A recycled metal sheet was placed on the roof as protection against rain. The legs of the main-frame were height adjustable so that the whole installation could be at balance on the uneven and coarse pavement of the Market Square.

4.4.5 ARTIFACT COLLECTION

Our initial conversations with the participants revealed a wide range of energy-using objects and artifacts in their domestic spaces as can be seen in Figure 4.36. We decided to curate a set of artifacts donated by the participants that were their favorite objects and relevant to the energy use in their homes. Our goal was to represent those artifacts through our open system to the broader audience.

The initial research questions addressed to the participants were:

1) What is your favorite object that needs electricity to function? Provide an image of that object or if possible the object itself. The image / object will be placed in the installation (size: 75 x 75 mm), aiming to anonymously represent you in the public place along with your lamp which will convey your daily energy use with its brightness.

2) You are also requested to write a few sentences like a small story about the object, its power consumption as you know it and your relationship with the object. If this object/ electrical artifact could become obsolete in a post-oil future due to an energy crisis or such environmental issues, what is it that you will miss about the object? As shown earlier in figure 4.17., we also asked them to mark the location of the object in their domestic space on the plans of their residences. A paragraph narrative (in Finnish or English language) was requested from them that described their relationship with the object, their feelings and emotions associated with it.

However, a majority of the electrical objects submitted by the participants turned out to be at a scale beyond the size of the installation. The objects collected from the domestic spaces ranged

Fig. 4.29. Community contributed electrical artifacts for the installation:

ILLUMINATED GLOBE:“Karttapallo on lahja rakkaalta ystävltämme, joka tiesi kummankin meistä pitävän karttapalloista. Hän löysi sen kirpputorilta. Meille se symboloi matkustelua, joka on rakkain harrastuksemme. Tämä rakas harrastus muuttuu huomattavasti harvinaisemmaksi iloksi, kun halvan öljyn törsääminen loppuu. Karttapallo ja sen lämmin 80-lukulainen valo tuovat lisäksi muistoja lapsuudesta,” Participant: E & T.

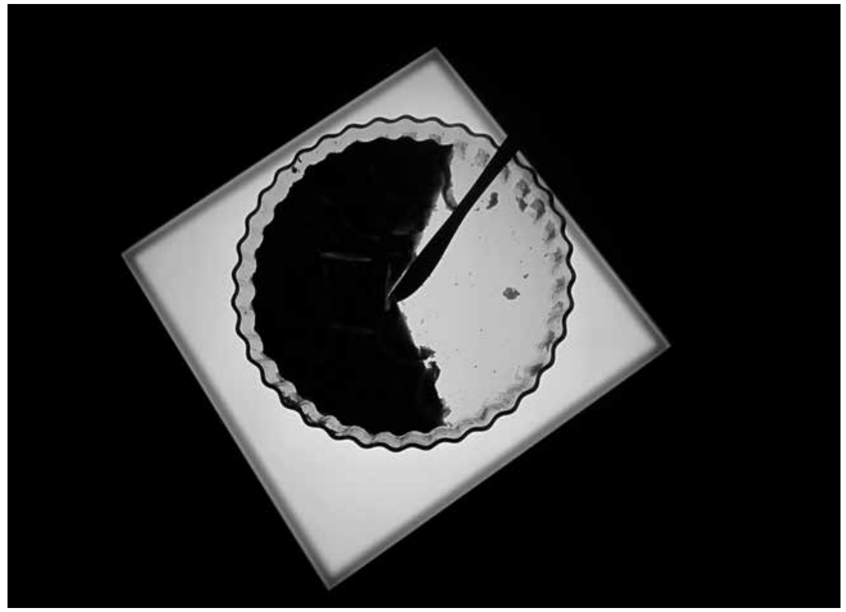
ELECTRIC STOVE: “We have a stove. We love it. It works by induction. We had to replace some of our pots and pans when we installed it a few years ago, but cooking on it is really so much more fun than on the old one that it was very much worth it. It’s also more energy-efficient than a regular electric or gas stove. It could use better switches, though, the touch switches are a bit annoying when we spill something on them for example. As oil grows scarcer, it will gradually be displaced by other forms of energy. Energy is likely to get somewhat more expensive, although at a Finnish standard of living this won’t impact daily life much. Electricity will have to get a great deal more expensive before it becomes a serious factor to consider when deciding whether to stew or sauté something. Scarcer oil is certainly unlikely to obsolete our stove during its expected lifetime. It’s a good deal more likely we’ll have to move to higher ground because of rising sea levels before that,” Participant: JSS.

COFFEE CAPSULE: “This is something I could not survive without; being a mother of a 6 month old baby and suffering from a constant lack of sleep: A state of the art coffee machine which ensures that I can have a quick cup of coffee when ever I have the need for a little pick me up. The Nespresso machine uses these small capsules to make strong espresso, an absolute necessity every morning, noon and afternoon,” Participant: P.

VIDEO PROJECTOR: “My favorite electrical object is a mini video projector. I use it mostly for watching movies, but it has been useful while working with media art as well. It uses quite small amount of electricity,” Participant: J.

LAPTOP: “Rakkain sähkölaitteeni, kannettava tietokoneeni, 15 tuumainen Macbook Pro on tuonut elämääni sisältöä jo viisi vuotta. Suurimman osan kotona vietämästäni ajasta olen kuluttanut sängylläni maaten Macbook Pro mahallani. Kuvauspäivänä se ei yllättäen käynnistynytkään, vaan makasi sängylläni kylmänä ja elottomana. Ilmeisesti siihen oli tullut jonkinlainen sähkövika. Olin surullinen, mutta tyytyväinen että sain vihdoin syyn käydä ostamassa tilalle uuden Macbook Pron,” Participant: JK

RADIO: “Isäni hankki tämän aikansa high-tech-laitteen, Salora Orthoperspecta -radion kaiuttimineen 1970-luvun alkupuolella. Sain sen omaan käyttööni 6-vuotiaana, viitisentoista vuotta myöhemmin. Lapsena ja nuorena Rovaniemellä asuessani radioni toi maailman huoneeseeni - tapahtumat, tarinat ja varsinkin musiikin. Pidän edelleen ison kaiuttimen saundista ja radion suurista, selkeistä painikkeista. Radiota on huollettu useita kertoja. Sen tyyppivika ilmenee aina välillä: se selaa itsestään lähekkäisillä taajuuksilla olevia kanavia. Tämä sielukas laite on edelleen päivittäisessä käytössä kotonani,” Participant: PM.



LAMP: “I got the red table lamp from my dear friends who moved to Chicago and San Francisco. It reminds me of them, of their warmness and generosity. As it does not fit with the style of the house, I had to create a suitable space in the kitchen: the philosophical corner. The aim of the corner is to be enough pop to discuss with lightness about politics, taboos and idealistic ideas. The corner is a work-in-progress, ideal for consuming strong Italian espresso coffee,” Participant: SV.

ELECTRIC SAUNA: “Olen itkenyt, nauranut, rakastanut, eronnut, ollut hiljaa, mölynnyt, pitänyt jatkoja, ollut yksin, ollut kymmenen ihmisen kanssa pylly vasten pyllyä, laulanut, kertonut salaisuuksia, säveltänyt ja runoillut saunassa. Kun kiuas sanoo tsssh, mieli sanoo tsssh. Höyry on kuumaa ja kivet kauniita, sauna on mun juttu,” Participant: U.

from washing machines, light fixtures, laptops to espresso capsules. Most of the electricity using artifacts were lamps and light fixtures. The biggest energy consuming objects were a washing machine and a sauna electric stove. The least energy-consuming object was an electric toothbrush. All these objects represented a vivid depiction of energy-use in the Finnish home. And, to reduce energy consumption we decided against using any digital displays to depict this collection. So, we requested the participants to provide a photo documentary as a representation of the electrical artifacts.

Fig. 4.30. An image of a light fixture mounted on an antique wooden frame placed inside the vitrine.

The photo documentaries were printed and mounted inside old wooden photo frames sourced from an antique photography shop. The frames were ornate, miniatures, some with gold paints and rich varnishes. An underlying idea here was to enact the display of contemporary energy artifacts in a stylistic representation of old paintings in heritage museums. This strategy we figured could visually memorialize the energy artifacts as our material heritage and mimic the infrastructure of the museum in a public place.

We also installed text labels for every donated artifact. These texts were written by the participants about their relationship to their artifacts. For this, we studied how museums label their collection objects in their exhibition galleries. What was the typography, the font size, color and shape of the label? How much text should be presented to convey the necessary information? How much metadata should be displayed? We designed small metal sheets as label holders for the narratives of the participants. The labels accompanying the objects allowed us to understand the relationship of the participants with energy use of the donated artifact, i.e. how they perceived the presence of the artifact in their daily lives? These narratives were publicly displayed on the installation as shown in figure 4.24, and acted as a textual window to the participant's contemporary life with energy use. On the installation itself, the identities of the participants were anonymized and it was only through the images of the energy artifacts and narratives that any identity was provided.

4.5 SOFT MEDIA INFRASTRUCTURE

4.5.1 ADVANCED METER INFRASTRUCTURE

The introduction of Advanced Meter Infrastructure (AMI) and a web API that can remotely broadcast and capture energy data has raised questions of privacy and in extreme cases that of surveillance. While AMI could bring significant benefits, it is potentially subject to security violations such as tampering with the software in the meters, eavesdropping on its communication links, or abusing the copious amount of private data the new meters are able to collect. "With anticipated deployments of millions of advanced meters, high costs for replacing meters, and greater dependence on AMI for the stability and financial integrity of the power grid, these threats must be taken seriously."[54]

Since the monitored energy data of our participants was one of the crucial aspects to the working of the LAD modules, we had to take this into account in our project. Smart metering or not, HELEN denied us direct access to the participants data although they had handed over the rights to access their energy data to us. We attempted to connect our project to their energy data API, however HELEN cited national security and privacy issues related to our request. As such we had to design a manual procedure for reporting the data and supplied each participant with detailed instructions.

4.5.2 ENERGY PROVIDER API

The energy data produced by the local energy provider Helsingin Energia (HELEN) was key to our project. HELEN provides a closed API (application programming interface) for its customers to access their energy meter readings. This was as a result of Advanced Meter Infrastructuring (API) or smart metering introduced in early 2007 in the Helsinki metropolitan region. The system delivers instant data about the status and problems of the network and enables operations to be remotely performed. These functions contribute to faster response times, accurate billing and allows monitoring of one's own energy consumption.

The daily ritual consisted of logging into HELEN's online Sävel services (Finnish) which provided online energy consumption data of its customers, and noting down the daily reading and then transmitting that data to us through our designed web API.[55] This Login was restricted to the electricity bill account holders and the participants had to register online using their bill invoice number and the location number. Once logged in, the API took you to a page showing a column bar chart representing your daily consumption for a month. You could click on one of the bars and that would further lead you to a breakdown of your daily energy use. A scrolling list presented the data line by line. On a sidebar it was possible to select annual and even a 5 year consumption. This data could also be viewed as a line graph and as a comparison with previous reporting periods. These could be further downloaded in portable document and Microsoft Excel document formats. For the purpose of energy reporting to our project, the participants had to identify their daily meter readings from this array of

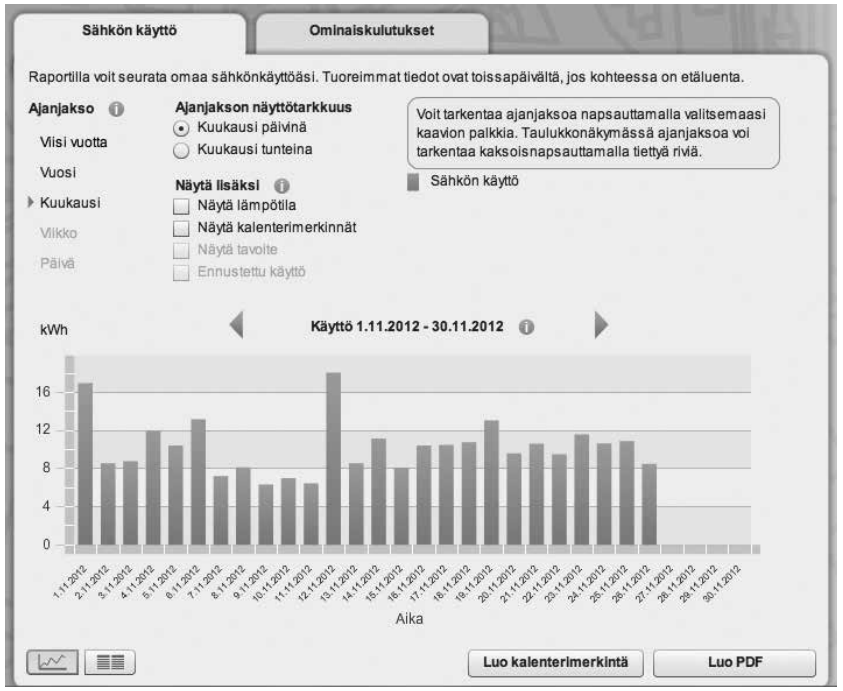


Fig. 4.31. Helsinki Energy's Sävel Plus, a household energy monitoring web application interface. Image shows the electricity consumption of a participant during the month of November 2012. All copyrights belong to Helsinki Energy.

visualized data and input it on our web API. This reporting was done rigorously for a continuous period of 10 days.

4.5.3 INFRASTRUCTURES FOR ONLINE ENROLLMENT AND PARTICIPATION

What media infrastructures are needed for initiating a participatory project? How to enroll participants to a museum installation that demanded active participation? How to broadcast the concept of the project to initiate the fostering of a local community? We designed several methods to announce the project to the local communities of Helsinki.

A website of the project was the starting point which displayed the goals and objectives.[56] It also contained an overview of the project and

Fig. 4.32. Website of the Light is History project.

a process gallery (the contents mirrored the project funding application and elaborated them further). The open calls for participation at the commencement of the project was posted on the homepage. The Wordpress website was minimal in design, mobile responsive and hosted on the Aalto University research server. Besides the homepage, the call for participation was broadcast on various online forums such as Sharetribe, Twitter, Facebook, local community blogs such as Möndåg, Helsingin Energia blog, and Aalto University community blogs such as Onni. A poster was designed, printed and posted at several prominent locations around the university premises.

As already mentioned briefly in 4.2, we designed an online survey on Google Documents and embedded a participation form in the homepage. The questions are as follows:

1. As part of a community art project are you willing to share your home electricity reading with us for one week, just once everyday?
2. Are you willing to give us one small object from your home that requires electricity to use for the art project?
3. Do you have your electricity meter located within your apartment that you can see everyday?
4. Is Helsingin Energia your energy service provider?
5. Do you carry with you a smart phone with internet access or a phone that can send SMS?

83% of the respondents were willing to share their daily electricity meter readings, a pre-requisite for the project and also willing to donate an electrical artifact from their homes. 75% had no visual access to their electricity meter, only 25% had the meter installed within their homes, although all respondents were supplied electricity by the local energy provider Helsingin Energia. All of them however carried a smartphone with internet access, another pre-requisite for the project to allow mobile delivery of energy data (the energy provider itself at this point had not deployed a native mobile application for its customers). By examining the most crucial questions of willingness to participate, sharing of energy data and energy-using artifact, the survey prepared the ground for the official signing up of the participants and the creation of a small community. As a result, we were able to sign up 16 families from the neighborhood of Kallio, Helsinki that in total included more than 30 individual participants from diverse age groups and nationalities.

From this group, we initiated a community group that in retrospect can be considered as a Community of Interest (CoI). According to Fischer – "CoIs are characterized by their shared interest in the framing and resolution of a design problem….they come together in the context of a specific project and dissolve after the project has ended."[57] Our CoI brought together our respondents of the survey from Kallio, from diverse backgrounds and practices, that worked collaboratively bringing together their expertise on an online community group on the Facebook social network platform. The online group had access to a discussion forum (the Facebook posting page), profile pages of individual respondents, and immediate access to online chat. Here, community discussions were held about the practical issues of co-producing the project in the neighborhood and energy use in daily living, art, museums and wellbeing. Fischer also says that – "the fundamental challenges facing CoIs are found in building a shared understanding of the task at hand, which often does not exist at the beginning, but is evolved incrementally and collaboratively and emerges in people's minds and in external artifacts."[58] Thus, through daily online interaction, the members of the community group soon became familiar to each other's points of view, exchanged ideas and thoughts and finally became acquainted with their daily energy use. Thus, the community not only shared common interests already before the physical installation was built but also had the advantage of providing insight into the placement of the project in their neighborhood.

LIGHT IS HISTORY WEB API 4.5.4

We designed a simple web API (application programming interface) that was also mobile responsive to collect electricity meter readings of the community participants. The API compiled daily reported readings as numerical values that reached a MYSQL (an open source database management system) database on a secure server. The database server then transmitted the value to the Arduino microcontroller embedded in the installation.

The intention of the API was to compute the daily differences in electricity consumption of the participants and transmit the same to the installation. Positive values (the difference between successive daily reports) were recorded when participants reduced their consumption, negative values when they consumed more. The positive values enabled an increase in intensities of the LED in the LAD modules. Whereas the negative values resulted in diminished light intensities. Thus the interface for reporting the daily meter readings was designed for daily inputs and display of positive or negative values. As shown in Figure 4.33., the early interface consisted of the name of the participant, 3 separate columns: date, energy units and daily difference and a submit button. The date was the day of reading the electricity meter (usually early mornings) by the participant, the units in kilo-watt-hours and the daily difference was the computational result between two successive daily reports.

The background of the interface was designed to be black in color to allow the numerical values (font type was Helvetica) to be prominent. In the following version, as depicted in figure 4.33. we also experimented with a graphic background without causing any visual confusion to the participant. In the daily difference column, the font colors were tuned to depict various levels of energy savings (directly related to the light intensities on the installation). Bright green was used to show substantial energy savings followed by light green, both of which represented positive values. Red and light brown as negative values,.i.e. negative energy savings over consecutive energy reporting. The participant was provided with a dedicated data feed link (an IP address) to the API, and their data was stored in the secure MySQL database.

4.5.5 CONTROL ALGORITHM AND LAMP CONTROL SPECIFICATIONS

A sketch was written in the C programming language within the Arduino Integrated Development Environment (IDE) for the light control of the installation.[59] This was a short program uploaded to and run on the Arduino board. The sketch computed the meter reading entries and produced variable light intensities over a period of 2 hours between 1700 and 1900. This was encoded in the setup and loop functions of the Arduino sketch.

The Setup Function: The Lamps had 4 states of brightness. VERY DIM, DIM, BRIGHT AND VERY BRIGHT. VERY DIM if the value was negative between two consecutive entries and the difference in consumption was more than 0.5 kWh. DIM if the value was negative and difference in consumption less than 0.5 kWh. BRIGHT if the value was positive but the difference in consumption was less than 0.5 kWh. VERY BRIGHT if the value was positive and difference in consumption was more than 0.5 kWh.

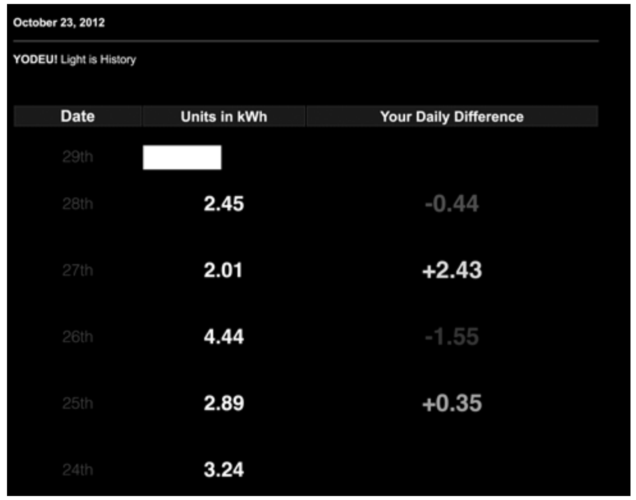


Fig. 4.33. *Left*, Initial interface of Light is History web application; *right*, Advanced interface of Light is History web application.

The Loop Function: The states of brightness was based on 15 minute cycles over a period of 120 minutes, i.e. from 1700 until 1900 hours daily during the period of the installation. At 1700, all the lights were VERY BRIGHT and then over a period of 15 minutes i.e. at 1715 the lights remained VERY BRIGHT or changed to BRIGHT, DIM OR VERY DIM according to the meter reading entries. At 1730 the lights converted to a VERY BRIGHT state. At 1745, the cycle was repeated (they were again depicting the state of consumption of the participants). At 1800 they were VERY BRIGHT, at 1815, showing the state of consumption again, 1830 back to VERY BRIGHT and at 1845 depicting the state of consumption and at 19.00 ending with a state of VERY BRIGHT.

Thus the energy savings of the participants was visualized through the various states of brightness and dimness of the lamps. The Arduino sketch was key to this visualization.

Fig. 4.34. A sketch of the project algorithm.

4.5.6 ARCHIVE AS DATA COLLECTION METHOD

We designed and deployed a digital archive to house the artifacts of the participants online on Tumblr, a micro-blogging and social networking platform. Tumblr allows following, re-blogging and building linkages through micro-posts. It has a simple uncluttered interface from which one can manage and maintain multiple archives and also an appealing end-user interface. Besides Tumblr themes are easily available and is known to be widespread in the cultural community.

We uploaded the images of the energy artifacts of the participants along with their personal narratives on a Tumblr theme. The identity of the

TABLE 4.1. Example of a Daily Consumption Difference Light State

23rd Aug Tue	1.9 (kWh)		
24th Wed	2.27	0.37	Dim
25th Thu	2.29	0.02	Dim
26th Fri	1.5	0.79	Very Bright
27th Sat	2.39	0.89	Very Dim
28th Sun	1.99	0.4	Bright
29th Mon	1.72	0.27	Bright
30st Tue	1.81	0.09	Dim
31st Wed	2.54	0.73	Very Dim
1st Sept Thu	1.73	0.81	Very Bright
2nd Fri	1.42	0.31	Bright
3rd Sat	2.7	1.28	Very Dim
4th Sun	5.88	3.18	Very Dim
5th Mon	1.84	4.04	Very Bright
6th Tue	1.67	0.17	Bright

Fig. 4.35. A virtual repository of community contributed artifacts.

participants were not disclosed as per earlier agreement with them. An about page described the project, its process and outcomes. We included a submission form on a separate page to encourage online participation by other citizens willing to donate their energy artifacts and stories.

This archive demonstrates our use of Tumblr as a tool to share small packets of content serially and easily to bring contemporary energy artifacts to new online audiences. The internal structure can enable the presentation of artifacts over time through scheduled sequences of daily posts. The image-focus of the platform allows content to be developed and published rapidly. Our Tumblr archive has – "the dual function of contributing to a mass of online visual information; "participating in an existing world-wide dialogue, while also functioning critically, providing a vehicle for data collection thus acting as an ongoing and potentially infinite piece of 'living' research."[60]

4.6 TRIALS, INSTALLATION & FEEDBACK

4.6.1 SINGLE MODULE TRIAL 1

Prior to the actual installation, the project was first simulated in a D.I.Y. festival connected to the emerging maker culture: Wärkfest 2012 (20.10) in Helsinki. [61]The first modular unit shown in figure 4.36., consisting of a therapy lamp and a display case was installed on a mannequin borrowed from the Fashion Department for a temporary installation in the exhibition hall.

There were a considerable amount of visitors and people from the DIY community visiting our temporary installation and provided us critical feedback. First, such personalization of energy consumption and visualization would work best if the final installation on the Market Square continued the theme of anthropomorphic human-sized mannequins rather than in the shape of an electrical box. Secondly, that the installation should be for a longer period of time visible on the square than just for a week.

Fig. 4.36. *Left*, Installing the LAD module onto a mannequin; *right*, Trial at the Wärk Festival 2012.

We also presented the project and the demo LAD module in a project presentation session. Information about the final installation, participation forms and recycled electrical meters were on display at our desk. Young adults were especially interested in all the inside workings and parts of the electrical meters, one even took home a few pieces, and came back next morning to show his own light gadget that he had created overnight. The event allowed us to sign up new participants and distribute information to prospective communities. Most who signed up were interested in the participatory aspect of donating energy for light therapy in public and also about the community interaction it could generate at the site of the installation. Among others were also visitors who cared about saving energy and reducing their carbon footprint.

4.6.2 SINGLE MODULE TRIAL 2

The project was also simulated in an exhibition connected to an academic workshop: The Media of Energy and Emotions(MDNM) at the Aalto University in 2012 (12.11 - 17.11.2012).[62] The MDNM project –

> *"aimed to generate a multidisciplinary platform for artists, designers and researchers within Aalto University, to create new*

connections between media, energy and emotions. With an emphasis on the emotions induced by interactions in everyday life, it focused to explore the relation between the design of objects, the use of electricity, and our perceptions and responses towards their interplay."

Fig. 4.37. Trial 2 at the MDNM Exhibition 2012.

For the exhibition, a single LAD module was outfitted on a mannequin, an articulated life-sized doll, the same that was borrowed from the Fashion Department of the University. The original head of the mannequin was removed and in its place the LAD module was attached. The module itself was affixed to plywood base conforming to the outlines of the electricity meters. Holes were punched on the base to pass the power supply to the LAD. The mannequin was attired in classic Indian costume: the sari. In this test, we did not place any artifact within the LAD, nor any narratives. The test exposed design issues such as the eye-level visibility of the artifacts and the positioning of the therapy lamp. It also showed the limitations of the bright light intensities of the LED strips within an enclosed space.

FINAL INSTALLATION 4.6.3

Despite critical feedback about the form of the final installation and the effectiveness of the light intensities, we proceeded to installing the mainframe with the LADs attached at Hakaniemi Market Square towards the end of November. Officially, the installation operated between November 25 to December 1 2012 as a co-created community museum space, an outcome of the community participatory and self-publishing activities, as described in sections 4.3.5. and 4.5.3. It simulated during this time on site the energy savings data of the community participants and displayed their domestic energy artifacts. The identities of the participants were anonymized and it was only through the images of the energy artifacts and narratives that any identity was provided on the installation. The LAD module (therapy lamp combined with the artifact display case) and the narratives presented the identity of the anonymous energy provider in the public square.

Fig. 4.38. Final Installation at Hakaniemi Market Square, November 25, 2012.

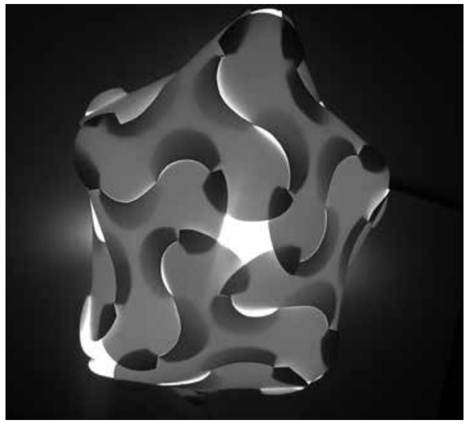
We enacted a daily ritual or practice at the market square. This involved gathering the participants at the installation when it was powered on between 1700 and 1900. Coffee and Glöggi (a traditional Finnish Christmas drink) was served during this time. In the course of the two hours, the anonymous participants and the general neighborhood audience were able to assemble around the donated energy of the lights and the artifacts collection. On each days of the installation, we constructed an experience at the public square in which the audience and the participants inhabited the installation space to formally engage in conversation.

Fig. 4.39. A visit by school children to the installation.

Discussions were initiated on-site with the participants about public light therapy, wellbeing, energy artifacts, museums and acts of community participation including conversations about open publishing of energy data, feel-good aspects of energy saving, use of appliances and the emotions associated with it. Non-participating members of the local community, visiting researchers and faculty members also attended the discussions. Students accompanied by their teachers visited the installation several times during the day and received information and lessons in energy use and saving. Between multiple enactments in the week, the curious local residents, elderly and passers-by often lingered to gaze at the artifacts, browse the narratives and engage in conversation with the participants. Some of the narratives generated more discussion than the others (Appendix contains all the submitted narratives).

Fig. 4.40. Community contributed electrical artifacts:

COMPUTER: “This is our computer. We call it Cadillac. It’s big and doesn’t have much power so it’s often quite slow in its moves. Its looks and many shiny lights have the ostentatious looks of an american car. Cadillac is a part of this installation because of our complex relationship. On one hand we spend a lot of time together so it seems we enjoy each other’s company but it often annoys and frustrates us. In our opinion we don’t cause its problems and yet we always have to fix them. In Facebook terms our relationship status is complicated, “ Participant: A & T.



LAMP: “This object used in the darkness delivers warm and light. My behavior of pressing the switch is directly related to such effect bringing me positive energy,” Participant: BY.

TURNTABLE: “The turntable is almost as old as the oldest member of our household and it has been with us for a very long time. The power it pulls from the electricity grid is minuscule compared to the power of the experiences it has provided us over the years. While the object is only a conduit for the music passing through its parts, it has become an important part of our everyday existence,” Participant: J.

CAMERA: “Kamera on osa minua, luovuuteni instrumentti. Kuvatessani mieli, sydän ja kädet virtaavat yhdessä saman päämäärän hyväksi, hlljentäen ajatukseni. Näin syntyvä kuva on kuin hedelmä, jota kaikki sen näkevät pääsevät maistamaan,” Participant: KS.

WATER BOILER: “Vedenkeittimemme on häälahja 10 vuoden takaa. Kun kirjoittaminen ei suju, keitän itselleni kupillisen murukahvia. Vedenkeitin kohisee järkeä ja toimintatarmoa. Sen metallipinta heijastaa koko keittiön, minutkin! Varmasti itkisin, jos se hajoaisi,” Participant: MM.

LAMP: “Valaisin on kotimme rakkain sähkölaite, koska se sekä valaisee että on kaunis. Suurin osa muista sähkölaitteista on vain hyödyllisiä, mutta tämä valaisin tuo iloa myös silloin kun sitä ei käytä,” Particpant: PJ.

ELECTRIC TOOTHBRUSH: “I got this toothbrush as a gift to myself. The wish of possessing such a thing came from my personal consciousness about my teeth (yeah, I like smiling and I do it a lot!). This brush works perfectly: it is much more effective in cleaning, comparing to mechanical brushes. What I also appreciate is that it allows me to be lazy, especially in the morning time, i.e. it does the job literally by itself, with its own power (electric). In addition to the above, it is a “long-living object”: there is no need to change the whole brush every three months, only a part of it. In other words, it is always the same thing: in terms of material, colour, weight, even noise, i.e. all haptic, visual and audial features. Therefore it provides a kind of ‘homey feeling’, at least the feeling of something which is truly yours and deeply familiar,” Participant: SU.

WASHING MACHINE: “Pyykinpesukone on arjessamme tärkeä. Se kuluttaa sähköä noin 1 kWh verran jokaisella pesukerralla. Vauvan synnyttyä pesukone on pyörinyt lähes päivittäin. Pesuohjelman loputtua kone soittaa hauskan melodian. Me kutsumme sitä serenardiksi,”Particopant: V & L.

Three energy artifacts stood out in terms of generation of personal wellbeing in the private space of the participants: One of the artifacts of the installation contributed by an anonymous participant was an electric sauna. This is a common household energy appliance in a Finnish home. Yet, it has deep links to the Finnish culture and history and can thereby considered a heritage. The stories associated with the Sauna is also part of the contemporary culture. It is featured in films, novels, dance and historical sites, all connected with stories and narratives. At the installation itself, the participant states her own thoughts about the energy artifact:

Fig. 4.41. An electric sauna stove.

I have cried, laughed, loved, broke up, been quiet, thought loud, partied, been alone and among people, sang, told secrets, composed poems and music in the sauna. When the stove says tsssh, the mind says tsssh. The steam is hot and the stones are beautiful..... sauna is my thing.

And, this statement can easily be attributed to much of the masses, who derive wellbeing from this energy artifact, a much apparent fact that an energy consuming historical artifact has an undeniable presence in the contemporary lives of the local people.

An old radio, an "Orthoperspecta" was submitted by another participant:

My father purchased this time of high-tech equipment, Salora Orthoperspecta Radio with speakers in the early 1970s. I got it for my personal use at age 6, some fifteen years later. As a child and as a young girl in Rovaniemi my radio launched a world of events,

Fig. 4.42. An old radio.

stories, and especially music into my room. I still see a big speaker, the sound of the radio is big, it's controls clear. The Radio has been serviced several times already. Errors occur from time to time: the scrolling controls itself the closely neighboring frequencies of the channels. Soulful, this device is still in daily use at home.

An illuminated world globe, from a couple in the community neighborhood, along with their narrative stated an apprehension about future energy crises and how that would affect their traveling plans:

This globe is a gift from one of our dear friend, who knew that both of us like globes. He found it in a flea market. For us, it is a symbol of traveling, which is the most cherished hobby. This great hobby will become less of a delight when cheap oil runs out. The globe and its warm 80s-style lighting in addition brings back memories of our childhood.

These short narratives provided a deep insight into the participant's energy life to the general audience on the market square. The local residents were also inspired that neighbors from their own local community were saving energy for the therapy lamps to serve the general wellbeing. This generated discussion about donation of energy

Fig. 4.43. An Illuminated globe.

and usually the topic dominated most conversations. Thus, for seven evenings, our project fueled a discussion with the local community in this public and visible square of Helsinki.

Interactions observed during the installation:

1. Several were observed moving around the installation from side to side, panel to panel, and when asked, said that they were trying to link the artifact image with the narrative and trying to link all the artifacts and their narratives.
2. Touching the LAD modules was also common among the residents, who poked at the glass casings or touched the metal sheet-mounted narratives.
3. Fear of electrical installations (and perhaps the possibility of electrical shock) kept some of the people away from the installation. This might be due to the fact that the installation appeared visually more like an electricity substation rather than as a conventional street art installation.

POST-INSTALLATION FEEDBACK 4.6.4

After the installation we initiated a feedback mechanism for the participants. An online questionnaire was created in Google Documents and emailed to the participants. The questions and some selected responses are compiled below from 6 participants:

A. ENERGY DATA PUBLISHING

Describe your experience of noting your energy use over a period of ten days. (For example what were your thoughts when you saw the value of your energy use on the screen daily and what did you feel about doing this over the duration of ten days?)

Participant 1:

I was interested in seeing how the numbers were fluctuating. And when I saw the peak(my 3.0), I gave a serious thought why. However, I do not think these behaviors influenced me much both physically and emotionally. Or maybe, anyway, I think I consumed little.

Participant 2:

I felt bad when my consumption had been higher than previously and I got satisfaction from noticing I had used less electricity. I noticed that when I made a mistake writing a value, I was able to overwrite it. That was a good feature, but it could have been also mentioned somewhere on the page. However, Sävel didn't work so well. There were a few days when the value was just 0. That made the experiment sometimes a bit frustrating.

Participant 3:

Following the energy usage daily gave me lots of practical information about different task with electric devices, e.g. it was interesting to see how making the morning coffee was clearly visible on the graphics. In addition, it was easy to see on which days we had not been at home.

Participant 4:

It was addictive! When the project finished, I still continued to see *the daily consuption! It was interesting to see the daily differences - I also made some small changes in the apartment to see it they would have an effect, ie. I turned the electrical heating down a bit in the bathroom. I also noticed that having a baby in the household really increases our energy consumption! (Washing machine on everyday, dishwasher on everyday, more lights on in the night, etc.)*

Participant 5:

I have been following our energy usage also before this project so there were no new experiences.

Participant 6:

It was a nice, fun and learning experience. It became a routine to check the numbers and send them every morning. We didn't try to lower our energy consumption, but became aware that we could plan it better. Seeing the green numbers on the screens was definitely a happy moment.

Summary: The installation succeeded in engaging the participants in the act of daily energy data publishing. This act caused them to critically examine their domestic energy appliances and their energy consumption. Some were even inspired to cut back on daily energy use.

B. INTERFACE

What did you think of the interface that you used to input your daily energy use information? What part you liked, what not and what could be improved?

Participant 1:

I do not like the dark background generally. And the colors, red and green, made little sense to me. The way of inputting was quite convenient, especially the way of correcting. The font was too bold for me. It would be better to see charts or patterns rather than numbers. I always did the input from the mobile phone. So it appeared that it was not adjusted for the phone screen.

Participant 2:

It worked well. Quick and simple to use. I'd maybe add some table where you could quickly see the daily consumption as a whole. I noticed that when I made a mistake writing a value, I was able to overwrite it. That was a good feature, but it could have been also mentioned somewhere on the page. In Finnish we write decimals with comma. In the form it didn't work. Maybe both comma and dot could be accepted? eg. 3,5 and 3.5

Participant 3:

GOOD: Clear, no extra elements or information, simple and strong colours, not much work to fill, easy to understand and read. BAD: Too big on laptop screen > easy to 'loose' info below the screen, did not work on iPhone. The date felt first misleading because it was not the actual day reported (but eventually I understood it didn't matter). I thought it was not that interesting to see how much my consumption had changed from the previous day. Instead, the average consumption from a year or in similar households might have been more interesting. But I understand it would have been much more complicated to realize.

Participant 4:

It was very simple. It was good to see the previous readings. Participant 5: It was ok, though there were some problems also. If you typed dot (.), it changed the numbers - for example when I typed 3.22, the interface changed it to 3.00. When you typed with comma, it worked like it supposed to work. Other problem was that you could report only one number per day. Sävel did not work that well and I got 0-3 numbers at time, so I could only report one of them and I was not sure which of them I should have reported.

Participant 6:

It was minimalistic and that was quite appropriate.

Summary: The web API was not mature according to many participants. The data entry could have resulted in a visualization within the API itself. Although, it was a simple to use application, it did not consistently perform and there were several instances where energy data had to be inputed manually. The calculation of daily energy savings also needs to be properly conceptualized. The shortcomings of the energy API can be attributed due to a lack of participation and most certainly this should have been co-designed with community.

C. INSTALLATION

What did you think of the art installation that was showing your energy use at Hakaniemi?

Participant 1:
It was really nice in the dark Finnish winter evening. However, the change of the dimness and lightness was too invisible to make sense. I like the part of text description, especially the material of board.

Participant 2:
I liked it. To my eyes it was a bit difficult to see the brightness differences, so if possible they could be bigger.

Participant 3:
It was small, sympathetic, easy to approach, clumsy (also in a good way), self-made-style, seemed to make people curious, which is great. Some parts of the installation were too high.

Participant 4:
I liked it :-) The lamps and the attached text was quite small, you really needed a close look to see the information - especially as it was so dark.

Participant 5:
It was really cool! I think it would have been better if there would have been more information in Finnish, because reading and speaking English was maybe too much for some potentially interested people.

Participant 6:
The installation was suitable to the season and brought a nice light element to Hakaniemi. It was well executed and stylish. We didn't notice any change in the brightness of the light, which was disappointing.

Summary: The installation succeeded, according to most participants. It brought the participants' saved energy, their stories and artifacts to the public realm during a dark autumn. The lighting specification was not sufficient for the brightness and dimness of the lamps and as such the lamp artifact display modules were not properly illuminated. The language of the narratives could have been in Finnish so as to have a broader access to the local citizens.

D. PARTICIPATION

Did the participation in the project change your view about any particular issues in your daily life? If yes, please describe which ones and how?

Participant 1:
At least I am aware of the issue of energy shortage now. Maybe because anyway I am not heavy user, so this participation has influenced my behaviors concerning little.

Participant 2:
I have tried to save energy also before participating the project. I was inspired to change the energy saving lamps to led lamps, though. Also I became aware of Sävel service, which I had not used before.

Participant 3:
It's also interesting to notice the electricity companies have lots of information about our life! It would be great to make people have a look at their daily electricity consumptions more. But how to do that - I don't have answers ready. The interfaces indicating the daily usage should be very available, visible when you use the devices.

Participant 4:
Of course it highlighted the fact that a modern home is very energy consuming. I thought a lot about the reason for this and also the responsibility. Is the consumer/citizen responsible for their own small part - or is this a larger issue, that has to do with design of objects? Why does a tv on stand-by consume so much? Should we have sockets that "switch themselves off" during the night? (Instead of me walking around the house every night turning appliances off?) Why are houses so badly designed in terms of energy consumption?

Participant 5:

No.

Participant 6:

We are definitely more aware of how much energy we use. Also, we realise how much energy certain home appliances use, e.g. a day without laundry, dishwashing and cooking is quite low (by our standards!) in energy consumption.

Summary: Participation in this project made the local residents aware of energy consumption in their homes. During the project, they learned to access their energy data through the local energy provider's API. They also realized that considerable amount of private data was in the hands of energy companies. As such, the design intervention was successful in generating critical awareness of energy use.

4.6.5 ENERGY TRACKING & SELF-PUBLISHING ENERGY DATA

Between November 21 until December 1, the participants were requested to publish their daily energy consumption for 1 week using our web application. The data entry process involved logging into the local energy provider Helsingin Energia's customer online portal: Sävel, recording the data in kilo watt hour (kWh) and inputting the same data into the web application. The computed energy savings data was then relayed to the microcontroller onsite and used to determine the brightness and dimness of the individual LAD modules. Through this setup, individual energy savings were simulated through the lamps on the installation on a daily basis, along with the display of the participant's artifacts and narratives. Three participants' energy data is available below for analysis.

The energy data of the participants from the few samples above show a decrease in consumption during the installation phase and increased savings. The act of self-publishing energy consumption perhaps had an impact upon our participants, but a direct relation could not be established. In general, reporting energy use created awareness among the participants about energy consumption. It also made them

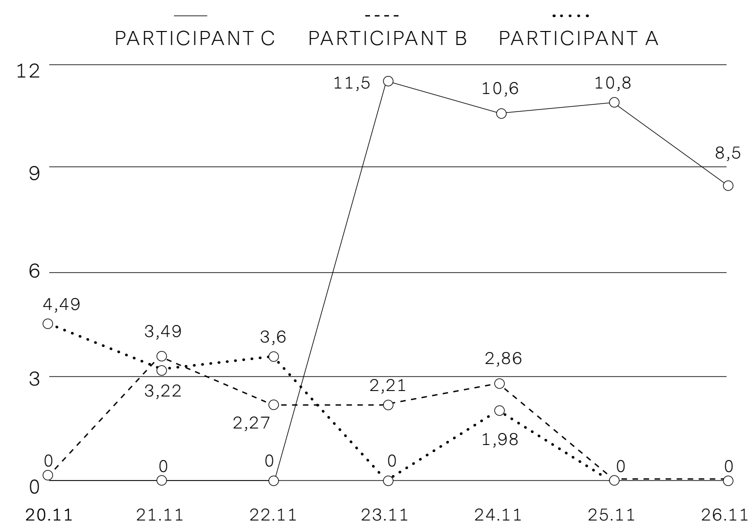


Fig. 4.44. Energy savings graph of 3 participants during the installation. (X=watts, Y=days).

realize the significance of all the electrical objects in their homes as part of their daily contemporary lifestyle such as: "It was interesting to see the daily differences - I also made some small changes in the apartment to see it they would have an effect ....." Some even decided to change their daily routines and save more energy. The bright lights on the installation according to their feedback: "it was very suitable to the dark autumn season and brought a nice light element to the Market Square in Hakaniemi." There were however some negative feedbacks especially that the artifact images on the installation were too small and small print narratives too hard to read. Another comment was that the narratives being partly in the English language was considered by a participant to be an obstacle in engaging the local Finnish speaking community. From the feedbacks we gathered it was however explicit that the participants became deeply engaged with the installation process in the aspects of energy data reporting and their relationships with the electrical artifacts from their homes.

4.7
INFRASTRUCTURAL ENERGY ANALYSIS

4.7.1
OVERVIEW

An estimation was initially made of the media infrastructure of Light is History. This included the computing hardware, interfaces and devices. The point of this exercise was to quantify the energy and emergy of the installation to demonstrate the energy efficient media infrastructure as opposed to a museum's media infrastructure (elaborated in 3.7). As already introduced earlier in 2.3., two components of energy are its embodied energy or emergy (the energy required to build the devices of the installation) and the other is the electricity use. The emergy of community contributed artifacts although initially evaluated were not considered for this analysis.

Table 4.2. Census of hard media infrastructure

COMPONENTS	QUANTITY	DETAILS
Electricity Meters	40	each weighs approx. 1 kilogram
Plywood (waterproof)	2	Various sized pieces (4,68 m2) - 18 kg
Microcontroller	1	Arduino MEGA 2560
Electrical Adaptor	1	10 watt
Cables & wires	5 meters	standard 22 AWG (american wire gauge) for electronics, insulated electrical wires for power supply - 1 kg
Laptop	1	MacBook pro and power adaptor.
Metal hardware	2 kilograms	screws, nuts, hinges, roof, legs etc. - 2 kg
LED strips	1950 centimeters	3528 SMD (surface-mounted-device) LED - 0,25 kg
Photo Frames	20	10 x 10 cm (approx.)
Metal Base for labels	20	10 x 10 cm
Acrylic Label stickers	20	10 x 10 cm
Prints	20	printed on photo paper using laser printer.

CENSUS
4.7.2

We have inventoried the various parts and components of the final installation in table 4.2. This includes the hard media infrastructure which was mainly composed of repurposed electric meters, wooden mainframe, LED strips, photo frames, metal labels and a microcontroller. We have not enumerated the participants' devices here (the same way that we did not inventory the museum visitor's devices to access the museum's content). That way we have restricted ourselves purely to the created or assembled materiality of the design intervention.

Table 4.3. Emergy of Media Infrastructure[64]

COMPONENTS	QUANTITY	PER-UNIT EMERGY Gigajoules (GJ) - per kilogram	TOTAL EMERGY Gigajoules (GJ)	REPLACEMENT TIMESPAN (years)
Electricity Meters	40 (40kg)	0,02	0,8	>20
Plywood	2 (18kg)	0,015	0,27	>10
Microcontroller	1	0,25	0,25	2
Electrical Adaptor	1 (10 watt)	0,1	0,1	1
Cables & wires	5 meters (1kg)	0,01	0,01	2
Laptop	1	4,5	4,5	4
Steel hardware	2 kilograms	0,02	0,04	>20
LED strips	1950 centimeters (0,25 kg)	0,1	0,025	>15
Photo Frames	20 (2 kg)	0,015	0,3	>20
Metal Base for labels	20 (1 kg)	0,02	0,02	>20
Acrylic Label stickers	20 (0,01kg)	0,077	0,00077	2
Prints	20 (0,02kg)	0,036	0,00072	1
TOTAL			6,31649	

EMERGY
4.7.3

Our project was not only a custodian of a collection of emergy artifacts but also an archive of the embodied energy contained within. Therefore the footprint of the installation was not only the power needed for operations but also all the energy used in the manufacture of its components. As discussed earlier in 2.3, the calculation of emergy is a complex process that involves taking into account the energy used to manufacture devices, the contribution from components and materials of the device, and recursively the emergy of those components and materials.[63] All end devices are enumerated in Table 4.3 and their corresponding emergy. These numbers have been gathered from a number of studies.

4.7.4. ENERGY CONSUMPTION OF MEDIA INFRASTRUCTURE

The energy consumption of hard and soft media infrastructure has been collated in the following sections.

The installation itself consumed little energy compared to the participant's homes. Over a period of 7 days, the total consumption was merely 2,66 kWh. The total cost to build it was < 500 euros. It comprised an area of < 1 sqm (site) and < 2 sqm (distributed).

1. LAD Module Consumption: 2,66 kWh
   [Calculations: 117 LEDs per lamp = 97,5 cm = 9,6 w per 100cm. X 16 = 153,6 watts total. This includes the LED 10w Adapter. Additionally, 9 LEDs per artifact display = 144 LEDs. The consumption of 1872 LEDs x 120 minutes = 0,38 kWh per day x 7 = 2,66 kWh]
2. Microcontroller Consumption: 0,0002325 kWh
   [similar Arduino UNO (at 16mhz, 5v); Power = 5v * 46.5mA = 232.5mW or, 0,0002325 kWh]
3. Total Consumption: 2,66 + 0,0002325 = 2,6602325 kWh.
   There are additional factors that have not been taken into account in our calculations. For example, our networked system depended on the electric grid (Fingrid) that already has massive emergy in terms of infrastructure. Power generation uses fossil fuels and there are losses in energy due to distribution. We have not considered the embodied energy of transmission infrastructure that is needed to deliver the energy data through the Internet, that includes equipment replacements and disposal. Software, such as the Arduino IDE and its emergy was not incorporated into our calculations.

RESULTS 4.7.5

The Light is History installation used 0,38 kWh per day, and in a week used 2,66 kWh of electrical energy (compare this to Cooper Hewitt's >190,5 kWh per month (2014) consumption when it was closed for renovations in figure 3.24, and 10,95 MWh per month when it was open in 2015). On average a household of 2 persons in Finland use 3 - 10 kWh per day. From our infrastructure inventory and respective emergy analysis, we found that the installation has an embodied value of 6,31 GJ (compare this to the emergy of Cooper Hewitt's media infrastructure which is approximately 1595,5 GJ).

SUMMARY 4.8

Our objective in Light is History was to simulate the infrastructure of a museum in a smaller low-energy scale in the public domain, as an alternative system powered by a community's energy savings. Our initial excavation into the community's energy life and diagrammatics of the museum allowed us to configure the project as a 'scaled systemic hack' of the museum. Our Critical Making methodologies then opened up hidden black box processes, allowed us to build a parallel open museum and visualize its energy consuming infrastructure. Through mimicking the workings of a museum we also engaged community, generated awareness of energy consumption and promoted wellbeing. Our energy analyses shows a low-energy consuming infrastructure that is also composed of low emergy.

A key methodology that developed within this design intervention was 'Critical Making'. Through this, we discovered how – hands-on-making could supplement and extend critical reflection on technology, energy and community, i.e. to be critically engaged with culture, history and society.[65] We attempted to blend various other methods such as reuse and remediation, microstructuring, self-publishing and fields such as architecture, design research, DIY, material culture and well-being. Light is History acted as a research object and as a speculative

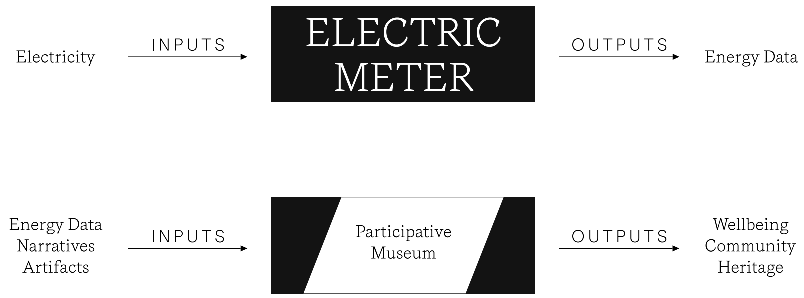


Fig. 4.45. The transformation of the electric meter black box into an ecological media.

artifact in the public space. The installation "generated speculations and possibilities to reason upon and to initiate critical enquiries."[66] The technologies we used were open source, and under constant collaborative development and as such could not become obsolete. We found that open source infrastructure was a low cost, low energy consuming bridge between personal spaces and public domain.

As makers and designers we coordinated every aspect of the project including research, design, circuit building, coding, construction of the mainframe, repurposing electricity meters, communications, cultural production and curating. Thus we gained considerable knowledge in the various fields of electronics, computer programming, API development, energy infrastructures, publishing and woodworking. This is a different approach than the digital strategies of museums such as the Cooper Hewitt that outsource their technology infrastructures to third-party vendors and tie themselves under long-term proprietary licenses.

The project brought together community residents of a local neighborhood, collaborated with them and was able to some degree, build a successful participative museum installation in an urban public square of Helsinki. The methodology of the intervention allowed residents to be engaged from the early stages of the design of the installation that included mapping of their homes, curation of energy artifacts and personal narratives. They were also able to participate in the daily operations of the installation, by donating their saved energy to the installation. This engagement lasted over several months, and was intensified during the days of the actual public installation. By the end of this experiment, after achieving the goal of the installation, this 'ephemeral community' had completely disbanded and disappeared.[67] Although the project did not have long term plans toward sustaining this particular community, the other community of Trashlab, the context of this design intervention that developed in parallel currently is a vibrant community of artists, researchers, hackers and makers. The Trashlab monthly events continue every year supported by Pixelache.

According to Boehner et al., "successful systems are not determined by whether or not a user 'got it right' or performed more efficiently.' Instead we look at metrics such as levels of engagement, enjoyment of use, integration with everyday experiences, the variability of use, or capacity for re-appropriation."[68] We began this project as an alternative model to the energy-intensive museum with several assumptions. Mainly, whether visibility of energy consumption and infrastructure increases 'openness' and reduces energy consumption in the long term and whether sharing/publishing/visualization of energy data & material heritage can lead to behavioral change. From our analyses, we have found that open-sourced 'critically-made' low-emergy media infrastructures can be responsible for decreased energy consumption. Through these infrastructures, community participants were willing to share artifacts, stories and save energy for the common wellbeing. Thus, a shared and collaborative installation in the public space that mimics a museum could be created outside the museum walls.

NOTES TO CHAPTER FOUR

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CRITICAL REMEDIATION

5.1 INTRODUCTION

For the second design intervention at the Gallen-Kallela Museum(GKM),[1] our goal was to design a "tactical engagement"[2] with digitization "to supplement and extend critical reflection"[3] about the materiality of the media infrastructures of the museum. As introduced in 1.8, we designed and developed a portable low-cost automated scanning system, a "remediated"[4] system that would aid small museums such as GKM with limited funds and personnel in digitizing their collections.

Fig. 5.1. The scanning system.

We organized community events around the digitization of the museum's collections and community-contributed artifacts, and around the principles of Culture Commons.[5] We attempted to simultaneously open up both the invisible digitization museum processes and visualize the energy consumption issues in open public workshops. We considered whether visibility of the digitization infrastructure encourages awareness, public participation and reduces energy consumption in the long term? Whether remediation of the existing digitization system in a new form and process could expose the museum's blackboxes and activate the museum's hidden infrastructure? Could our intervention serve as an alternative model to small museums in fostering their communities in the digitization and long-term conservation of heritage?

We conducted an initial excavation in section 5.2, of the history of telephotographic devices and the state of scanning technologies.[6] Preservation-level scanning systems such as a Cruse Scanner and related equipments in museums and archives are another area of black boxed technologies.[7] These are customized and expensive technical systems built primarily for institutions. They need dedicated and trained personnel to handle the operations and perform maintenance. They do not have a user community attached to the systems where troubleshooting advice could easily be found. Technical support has to be summoned from the manufacturers themselves. These systems are also difficult to fix and repair by the museum personnel and if broken, have to await for qualified technicians.

Then we examined existing processes and technologies utilized by the local museums and national archives (See methods of survey in 2.8). We found that digitization has been a back office activity of museums and archives. Except for the National Archives of Finland that uses automated robotic scanners, most other museums rely on manual off-the-shelf scanning systems. Most of the digitization facilities had grown as an unavoidable addition to the museum infrastructure and not planned and designed as a critical process of the museum. They had not (as of 2014) systemized their methods and compiled official benchmarks and standards.[8] Most relied on a few experienced personnel who conducted the digitization in dark back offices and cellars and who also doubled as machine technicians. This is as a result of low investment in the digitization activity within the organizations. Thus, it is currently estimated by the National Archives that it will reduce construction and storage costs of centralized extensive mass digitization of paper materials and outsource all mass digitization.[9]

This initial survey of the existing processes and technologies allowed us to develop our methodologies further. Our design intervention brought forward several key methods, critical terms and applications of infrastructure from the Light is History project (see 4.3). New iterations of the methods were applied to design and construct the infrastructure. Both designs share the methods of Critical Making,[10] Open Source and Microstructuring. These methods were initially introduced in 2.8. New approaches that emerged in this design intervention such as Critical Remediation and Community Sourcing will be discussed in 5.3.

Fig. 5.2. The Gallen-Kallela Museum.

Our design intervention was supported by a minimal media infrastructure (that will be discussed in 5.4). Most of the materiality was composed of a portable deployment platform that included a robot arm and a flatbed scanner, input and output trays as shown in figure 5.3. Additionally, a control laptop computer and power monitoring devices were attached to the system. The platform and the digitization computer were the most public-facing visible interfaces in the digitization workshops at the museum. The robot system UI on the computer was the main point of control of the scanning process. From here, the participants of the museum audience started digitization workflows, tagged artifacts and initiated the scanning session. Of all the infrastructure, only the robot circuit board, the Arduino microcontroller, suction pump and servo motor are concealed within a 3d printed casing.

The flat bed scanner embedded in the digitization platform is also another blackbox technology that we hacked and customized for the design intervention. The concealment resulted as we were apprehensive of the museum audience's reaction and affect to an all exposed prototype with visible components and cables. This mindset can also be attributed to a mental conditioning by consumer technological products that appear polished and clean on the outer appearance but hide black boxes within. There is also the question of technology and aesthetics that would go beyond the scope of this study.

Similar to Light is History, the soft media infrastructure for initiating our design intervention was a simple blog based on Wordpress, an open source content management system. Our announcements and communications to broadcast the design intervention and gather participants were assisted by the museum's own website and social media channel. We also composed and printed traditional A4 sized posters to convey the design intervention to the academic and museum community. A digital archive was designed and implemented to house the ephemeral collections of the museum and its community especially that of Finnish national artist Akseli Gallen-Kallela. Here the archive was constructed as a social network of Gallen-Kallela and his artist friends and acquaintances where their works were digitized and stored. This was the primary media infrastructure around which the processes of community artifact contribution and digitization took place during community theme days at the museum.

Prior to the digitization workshops at the museum, we conducted trials of the scanning system within the university departments of Computer Science and Design. This allowed us to gather feedback and design proposals for a portable deployment platform. Our scanning system was deployed publicly at the museum during 3 commu-

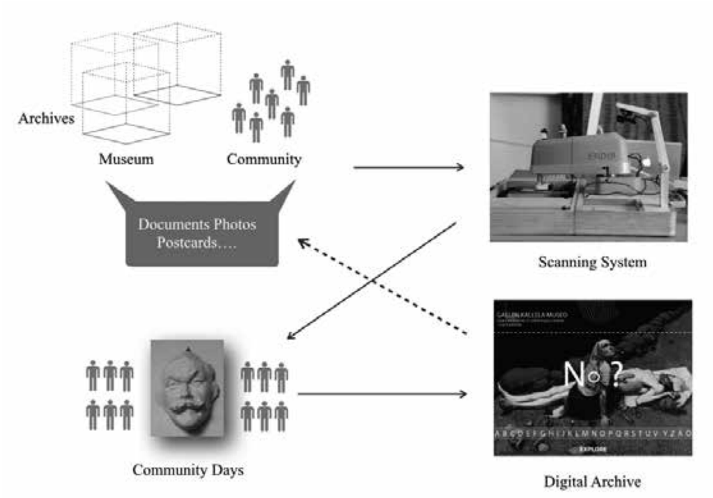


Fig. 5.3. System Diagram of the proposed design intervention at the Gallen-Kallela Museum.

nity theme days spread over 3 months. These short events were held in the exhibition galleries where the community's archival material was gathered for digitization. A designated area in the museum galleries was set aside for the digitization workshops. Donors of artifacts were assisted in using our digitizing system to scan their artifacts and upload to the digital archive. We also conducted panel discussions around the topics of art, archives and commons that especially dealt with copyrights and open knowledge. The last community theme day experimented with digitization and remixing the archive.

Our infrastructural energy analysis examined the various facets of the design intervention's energy use. We monitored the energy of the entire scanning system (power sources, robot, scanner and computer) during the digitization workshops. The museum audience witnessed the energy consumed in the digitization processes. We also calculated the embodied energy of our system - the energy needed to construct the devices and infrastructure that comprise our design intervention. The analyses demonstrate a low energy-consuming digitization system with low-emergy media infrastructures. Does such a system tactically inserted within a museum augment the engagement of the museum audience? Do the operations of the museum change as a result of this remediation?

The following sections contextualize the problem of digitization and small museums and recount the methodologies of remediation of the media infrastructures of our design intervention.We chronicle and analyze the potential re-activation of an old scanner into new settings. Through the trials, workshops and energy analyses we attempt to present the underlying energy concerns of the design intervention.

EXCAVATION 5.2

A BRIEF HISTORY OF THE IMAGE SCANNER 5.2.1

Scanners are remediations of telephotographic devices from the late nineteenth century. These analog machines were able to transmit photographs by telegraphic infrastructure, or i.e. electrical signals conveyed by dedicated telecommunication lines (telegraphy by itself is an ancient system of long-distance communication of textual messages without any physical exchange or medium in between). These involved not only the use and conductivity of electrical signals but also utilized the chemical process already discovered in photography.

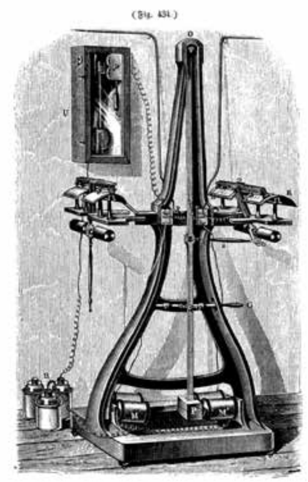


Fig. 5.4. The Pantelegraph by Giovanni Caselli (1856). Public Domain.

The Pantelegraph created by Giovanni Caselli in 1856 can be considered the earliest form of a telephotographic device.[11] Here, an image was made using parallel repetitive passes with a stylus with non-conductive ink on a piece of tin foil. The areas without ink conducted electricity which caused the circuits to switch on and off thus matching the image. These signals were then transmitted along a long distance telegraph line. The receiver also had an electrical stylus that traced blue dye ink on white paper, thereby reproducing the image line-by-line of the original image. A test was done successfully then between Paris and Amiens with the signature of the composer Gioacchino Rossini as the image sent and received, a distance of 140 km.[12] It was also used by the French Post/ telegraph agency in 1865-70 between Paris and Marseille.[13]

Fig. 5.5. The Belinograph BEP-2V telephotograph by Edouard Belin. Photograph by Sandstein, distributed under a CC BY-SA 3.0 license.

A more developed method came about in 1913 with the introduction of the Belinograph that scanned using a photocell and transmitted over phone lines.[14] According to Solbert et al., Alfred Korn, a professor at the University of Munich made a demonstration of a similar device, where a positive photograph on film was wrapped around a cylinder, which was caused to revolve. A narrow pencil-like beam of light was adjusted to shine on the cylinder, and the light which passed through the photograph was converted to electrical current by a selenium cell. The scanning light slowly traveled the length of the cylinder. The receiving set was not dissimilar, but was enclosed in an illumination-free box. Around the cylinder was wrapped photographic paper. A scanning light, modulated in brightness by the distant photo cell, slowly created exposures over the length and breadth of the paper.[15]

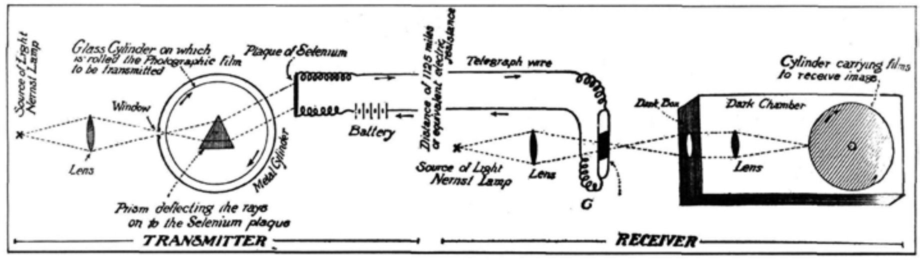


Fig. 5.6. Basic principle of Korn's wire transmission of photographs (1904). Illustration from the Scientific American, Feb 16, 1907, Public Domain.[16]

The first photograph was transmitted in 1921 by Western Union and then in 1924 by AT&T Labs. The process was such that a photographic transparency was mounted on a spinning drum and scanned. This data, transformed into electrical signals (proportional in intensity to the shades and tones of the image) were transmitted over phone lines and deposited onto a similarly spinning sheet of photographic negative film, which was then developed in a darkroom. The first fax images were 5x7 photographs sent to Manhattan from Cleveland and took seven minutes each to transmit.[17]

Fig. 5.7. The first scanned image, outcome of the first drum scanner to be used with a computer built in 1957 at the US National Bureau of Standards. The image was a 5 cm square (black and white, 176 pixels) of Russell A. Kirsch's three month old son. Photo courtesy of National Institute of Standards and Technology.

Today photocopying machines and scanners use the same principle as in the Belinograph. The only changes are that instead of a photodetector, they use a moving optical array of CCD (charge-coupled device) sensors in a flatbed scanner and photomultiplier tubes (vacuum tubes with extreme light sensitivity) in a drum roll scanner.[18] Already, by the end of 1990s, cheap consumer scanners were capable of scanning images at resolutions of 1200 or 2400 pixels per inch, producing digital images that contained far more information than one would ever want.[19] But beyond scanning, the devices today can process the scanned image with proprietary algorithms for image corrections and then send to a computer via the device's input/output interface such as through a Universal Serial Bus (USB) port. Currently, multipurpose scanners with wireless connectivity are available that can transmit scanned images over Wifi.

Table 5.1. A comparison of various scanning systems[20]

Scanner Type	Pros	Cons
Flatbed scanner	- Highly addressable - Inexpensive - Many units can handle both transmission and reflection materials - Flexible software drivers - Most good up to 600 dpi of real resolution. - Low learning curve	- Low productivity, frequent document handling - Tendency toward streaking and color misregistration - Prone to inflated marketing claims
Sheet-fed scanner	- High productivity As good as or better than flatbed scanners - Many automatic features	- Unsuitable for fragile, bound, wrinkled, 3-D, or inflexible objects - More expensive than flatbed scanners - May not handle all sizes of documents
Drum scanner	-Very high image quality · high resolution · low noise · high dynamic range · good tone/color fidelity · few artifacts - Very flexible software drivers - Variable sampling rate	- Expensive - Low productivity - Frequent handling - High operator skill level - Handles limited document types; must be mountable on drum
Camera	- Can handle a variety of document/ object types (3-D, bound, glass plates, non-flat, oversized) - Unlimited field size - User-controlled lighting. - Rapid capture for area arrays - Non-contact capture - May have interchangeable lenses - Generally good image quality	- Good models expensive. - Limited sensor size - Low productivity for linear array types - Nonuniformity artifacts common - Area array devices prone to low dynamic range due to flare - Moderate skill level required
Film scanner	- Highly productive for roll film - Low flare/ good dynamic range for linear arrays	- Low productivity for sheet film or slides - Potential for high flare in area-array devices - Dust/scratch artifacts common - Image quality characterization difficult due to lack of targets

5.2.2. TECHNICAL CRITERIA AND POWER CONSUMPTION

A variety of proprietary scanning systems are commercially available for image and document scanning. These are flatbed scanners, sheet-fed scanners, drum scanners, cameras, and film scanners. An analysis of the pros and cons of each device with respect to image quality, productivity, cost, and skill levels are presented in table 5.1.

The Library of Congress (LOC) has a tip sheet on choosing a scanner for archiving: of the five common types of scanners, three are well-suited for the safe handling of historical or heritage photographs: a flatbed scanner, a digital camera, and a film scanner.[21] A few key elements in a scanner define the quality of the resulting digital images and these could be benchmarked to understand the strengths and limitations of the system. This method also provides a quality control criteria. Thus, the elements to consider, according to LOC are:

Spatial Resolution:

"The scanner chosen should be able to achieve the desired spatial resolution for a digital image at the level of its optical resolution. The optical resolution of a scanner is the actual resolution the scanner can capture."[22]

Tone Reproduction:

"The reliable capture of tone in a digital image of a photograph is influenced by more than one element within the scanner. This includes its Bit-Depth Capture and Output, by which the scanner is capturing a higher bit-depth than the bit-depth specified for the digital image. This capability ensures that all of the relevant information is captured, whether or not the scanner allows you to output (save your file) at that higher bit-depth. The Dynamic Range / Flare of a scanner affects its ability to accurately represent the full tonal values of a variety of photographs, most notably the dark regions. The scanner should meet or match the dynamic range of the photographs being copied. In a digital image of a photograph, noise is the unwanted variation of data (bits) in the signal. Random signal variations within the scanner create digital image noise during the scanning of a photograph. Just like film grain can degrade the utility of a photograph, so too can electronic fluctuations in a scanner degrade the digital image by disrupting the tonal values that the scanner is supposed to capture. Finally, the scanner should support and accurately represent the color space choice for digital images. The color space should be cross-platform compatible, open and well-documented, and widely implemented and supported."[23]

Table 5.2. A comparison of power consumption of various scanners[24]

SCANNER TYPES	CURRENT CONSUMPTION	STAND-BY	SLEEP
Flatbed scanner (Cannon CanoScan LiDE 210)	2.5 w	1.4 w	11 mw
Sheet-fed scanner (Epson - WorkForce DS-510)	18 w	7 w	1.6 w
Drum scanner (ICG 369 HS Drum Scanner)	300 w	-	-
Camera (Hasselblad H5D-50 Medium Format DSLR Camera)	Li-ion battery (7.2VDC, 2900mAh)	-	-
Film scanner (PrimeFilm XE)	1.25A	-	-

For archival quality scanning, it is necessary to get the most out of the above elements from a scanner. Benchmarking the capabilities of a scanner is also crucial to the quality of scans. This should usually be the first step toward setting up a digitization program for any cultural heritage institution.

An overlooked aspect of selecting the ideal scanner systems for digitization is the power consumption. Drum scanners while delivering high image quality consume quite a bit of electricity and weigh upwards of fifteen kilograms. Flatbed scanners are the most energy efficient, but require plenty of manual handling and the image quality is not supreme.

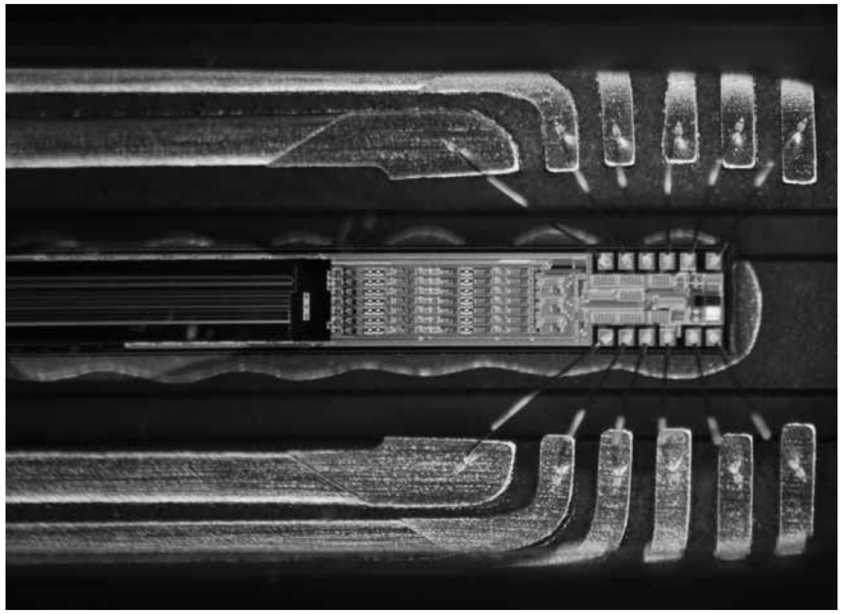


Fig. 5.8. Linear charge-coupled device (CCD) from a discarded flatbed scanner. The colored lines at the left are the CCD sensor itself and on either side, are a circuit and pads. Photograph by Micah Elizabeth Scott, distributed under a CC BY-SA 2.0 license.

Scanners are part of an ever increasing electronic waste and also a threat to the environment. Scanners contain mechanical components fabricated from steel, glass and plastics. Most contain fluorescent tubes which, given their required function, contain Mercury in a powder form.

5.2.3 DIGITIZATION OF HERITAGE COLLECTIONS

Digitization is often used to describe the scanning of analog sources into computers for further storage, processing and transmission. By digitizing sources whether they be image, sound, object, document or signal, they are transformed into a numerical format, i.e. binary numbers (digitized data or electronic code) that can then facilitate computer processing. These numbers become the digital representation of the original sources. Digitization allows the standardization of all formats and treats them equally whether they be object, image or document. The digitized form that exists as one of the two digits, 0 or 1, can be propagated infinitely without loss or decay as opposed to the decay of documents, photographs and degradation of objects.

Digitization in museums and libraries is the holistic process of scanning and storing digital representation of artifact collections using a variety of proprietary scanning technologies. Beaman and Cellinese say that digitization workflows – "span across human mediated processes through data and computationally intensive automation where software tools and services are the actors and intersect field collection techniques, institutional accession policy, differences in curatorial practice among domains, and involvement of the general public in crowd-sourced methods."[25] Initially, digitization efforts focused on assembling complete records and then access was granted only after extensive quality control – "recently, it has been recognized that not every element of a collection record needs to be recorded in a single digitization event."[26] However, several factors must be considered such as sensor resolution, pixel size, noise sensitivity, and cost. But, "collections inherently vary in the ways that physical objects and their associated data are stored, and differ in size, use cases, and available budgets."[27]

The challenge is therefore not only to digitize analog sources, but to understand the nature of the collections, to maintain and propagate digitized collections over a long period time. The formats in which digital information are stored, archived, and made available affect the use of digital media artifacts. This requires that the resources be available in standard formats with consistent vocabulary (metadata, annotations, color profiles etc.) and concepts, and protocols that are understood by every node in a network.

Digitization of existing collections is an enormous undertaking, yet can be a long-term investment in the propagation of knowledge. In this regard, 'linked data' environments would increase the possibility for the discovery of knowledge. Linked Data is a method for publishing and connecting structured data on the Internet. It creates typed links between data from different sources such as databases of organisations and is machine-readable – "its meaning is explicitly defined, it is linked to other external data sets, and can in turn be linked to from external data sets."[28] Currently, it is a challenge to discover cultural data across institutions and digital repositories in multiple domains.

5.2.4 THE STATE OF DIGITIZATION

At the end of 2008, Finnish libraries, museums and archives had 3.9 million digital objects in total. In 2011, the number of objects had increased to 20 million – the most extensive digitization projects were those administered by the National Archives, the National Library and the Finnish Museum of Natural History.[29] In early 2010, National Archives Service contained over 180 shelf-kilometers of permanently stored documentary material from eight centuries and approximately 1.7 million maps and drawings.[30] Currently, the digitization of heritage has been spearheaded by The Museum 2015 Project that has been developing and providing tools for electronic collection management and the development of museum collections.[31]

At the National Archives of Finland, the digitization of archival material is executed by a Cruse Scanner, a large format multi-function state of the art equipment. It can scan books, maps, paintings and transparencies. It uses high frequency cold-cathode lighting. It also has a power consumption of 4x55 watts, 115 VAC, 20A. There are post-processing computers along side. Two technical personnel are needed to digitize old maps and books.

The Strategy of the National Archives Report 2015 states that the costs for electronic storage will constitute a significant new cost item in the budget during the Museum 2015 strategy period.[33] Accordingly, the number of employees are supposed to be decreased by nearly 20 per cent during the strategy period. The maintenance and development of the electronic reception, storage and service system will require considerable resources. The National Archives Service says it will reduce construction and storage costs by centralized extensive mass digitization of paper materials to be received. The mass digitization will be outsourced and – "it will focus on materials that are suited to cost-

Fig. 5.9. A multi-function scanner system for books, maps, paintings and transparencies, Model: Archive Scanner System CS A SL300 by Cruse Digital Imaging Equipments.32 Image courtesy of Cruse Digital Imaging Equipments, Germany.

effective digitization, analogue or digital storage and paper material destruction procedures."[34]

In the Helsinki City Museum, the digitization process is on a much smaller scale.[35] Four personnel work on the image collections permanently. In 2013 over 9000 photos were digitized. Of each photo they make a TIFF (tagged image file format) version for basic use, an A3 sized 300 dpi version, and a digital negative. Scanners are no longer used anymore, only medium-format cameras. Thus, about 50-100 images of equal size can be processed in a day. Some of the metadata is added when the image is processed, some only once the image is added to the database. So part of the data moves with the image file. The museum runs an open photo archive office, with thousands of visitors per year. In the office, photos are organized by addresses in Helsinki. Visitors are able to browse these and buy prints.

The neighboring Swedish Literature Society (an archival institutions for the Swedish-speaking minority in Finland) had the basic infrastructure consisting of flat-bed scanners and medium-format cameras. Most archival material were donated and collected from the National Archives and other heritage institutions. Digitization itself was negligible within the offices of the institution. The Society had been using already-digitized material to develop online linked documents, data and linked maps.

Although, heritage institutions are on the fast track especially in the area of digitization, cloud collections, and interfacing with visitors and community, the cost and logistics of mass digitization has hampered the progress of transfer of cultural heritage assets to the web. Although these new approaches could be beneficial in the long run, they have raised the investment and energy use levels in digital infrastructures. These projects frequently require sacrifices in terms of scarce resources (money, personnel, and time) in order to meet long-term goals.[36] According to Katz, Koutroumpis and Callorda, for collections digitization to achieve a significant impact and be sustainable, digitization has to be widely diffused within the economic and social fabric of a given nation. For this to happen, it has to be adopted at three levels: "utilized by individuals, economic enterprises and societies, embedded in processes of production of goods and services, and relied upon to deliver public services."[37] For this condition to occur, they elaborate that digitization has to fulfill several conditions:

1. It has to be affordable to allow scalable impact.
2. It has to be ubiquitous (reaching most population of a national territory), and accessible by multiple fixed and mobile voice and data devices. It needs to be reliable, providing sufficient capacity to deliver vast amounts of information at speeds that do not hinder their effective use.
3. The challenge of the lack of tools to measure the impact that the mass adoption of connected digital technologies and applications are having on societies and economies needs to be addressed.

Today, digitization is also tied up with proprietary hardware, software and formats. Faber says that it is a constant reminder of the vulnerability of a museum's digital assets. According to him, – "in the world of digital imaging and digitization the current ubiquity of large proprietary brands can sometimes be seen as a hindrance when considering embarking on a digitization project."[38] Thus, proprietary formats can have support removed, or the format withdrawn altogether, leaving the institution without any clear course of action or redress.

After examining the various digitization infrastructures of museums and archives, we conducted a brief analysis of the few digitization tools in general available and used by heritage institutions in Finland and abroad. Here, we have not considered sheet-feed scanners and drum scanners since they are not suitable for small-sized ephemera. The main digitization tools are then large-format state-of-the-art scanners such as the Cruse Scanner, medium-format cameras such as the ones manufactured by Hasselblad, and off-the-shelf flatbed scanners made by Canon, Epson and Kodak.

From our analysis we have found that state-of-the-art large-format scanners are excellent tools for digitization and long-term preservation. They are durable, efficient and can handle a wide-range of media and produce high-quality scans. However they are large bulky machines that take up considerable space, require technically trained personnel, need dedicated servicing from the parent manufacturer and lack any sort of user community. Large-format scanners are also expensive to buy and operate. The medium-format cameras were slightly less expensive, and also produce high quality images. The cameras need special mounting structure and additional installation hardware, which in the end takes up to three to four square meters of museum space. Medium-format cameras have diverse online communities dedicated to repair and troubleshooting. Flatbed scanners were the cheapest and simplest to use. They are small and portable, use little energy and are easily serviceable. They have user communities online and are affordable for small institutions. Yet they lacked quality and were dependent on the manufacturer's bundled software. Although they don't require trained museum personnel, they are not durable nor efficient digitizing machines.

Table 5.3. A comparison of various scanning technologies used by heritage institutions

SCANNING TECHNOLOGY	SIZE	QUALITY	SERVICEABILITY	USER COMMUNITIES	COST
Large-Format Scanner	Large (Needs considerable amount of space, not portable).	High	Proprietary technology. Only serviced by the manufacturer.	Lacking.	Expensive, requires customization, and special order from manufacturer
Medium-tFormat Camera	Medium to Small (additional space and structure needed for digitization setup, not portable).	High.	Proprietary technology. Only serviced by the manufacturer or licensed agent.	Several online user communities made up of professionals and enthusiasts.	Expensive (but cheaper than large-format scanners). Also depends on the entire digitization setup.
Flatbed Scanner	Small and compact, portable. (Low productivity frequent document handling)	Medium to Low (good upto 600 dpi of real resolution).	Proprietary technology. Serviced by multiple agents.	Several online communities.	Affordable. Easily available off-the-shelf.

5.2.5 DIGITIZATION FOR SMALL MUSEUMS

Small heritage museums with limited manpower and funds are challenged to conduct digitization of their heritage collections and place their assets online. Digitization is often seen as an expensive undertaking with multiple software licenses needing large budgets. According to Thomas et al.:

> *"Small staff sizes, a lack of specialized expertise, dated technical infrastructures, and/or limited budgets create unique barriers for the professional tasked with stewarding digital content. When combined, these factors can create a seemingly insurmountable obstacle. Practitioners at smaller institutions often do not have time to stay abreast of the frequent developments in the field of digital preservation, may not have the expertise or technical infrastructure necessary to install and maintain complex software solutions, and frequently lack the funds to pay for complete, ready-to-use solutions that may exist. They are also in need of practical information with which to educate colleagues and administrators on the risks of digital content loss, advocate for necessary resources, and take initial technical steps to improve the preservation of their digital holdings."*[39]

Karvonen says that digitization has other issues as well: – "the challenges of digitization are manifold, – "covering large volumes of materials, increased complexity of materials, management of internal interrelationships between collection items, and future unforeseen technological advances."[40] A significant factor is the high price of proprietary industrial digitization equipment and associated costs of human resources. Digitization also needs constant investments in upgrading digital infrastructure and training of personnel. Especially, the human capital component, which is a key factor for the impact of digitization. Smaller museums located in semi-urban and rural areas of Finland have limited budgets and staff for such initiatives.[41]

DIGITIZATION AT GALLEN-KALLELA MUSEUM 5.2.6

Gallen-Kallela Museum (GKM) in Espoo, Finland is an example of a heritage art museum that is facing such challenges.[42] The museum is dedicated to the work of Finnish national artist Akseli Gallen-Kallela (AGK). As of mid-2014, it had an annual budget of 600,000 euros and six employees.

The museum is located in Tarvaspää, the atelier designed by Akseli Gallen-Kallela, built between 1911 -1913. The historic building site in Espoo adjoins the bay of Laajalahti in the south and by the Turku highway in the north. It is 10 kilometers from the center of downtown

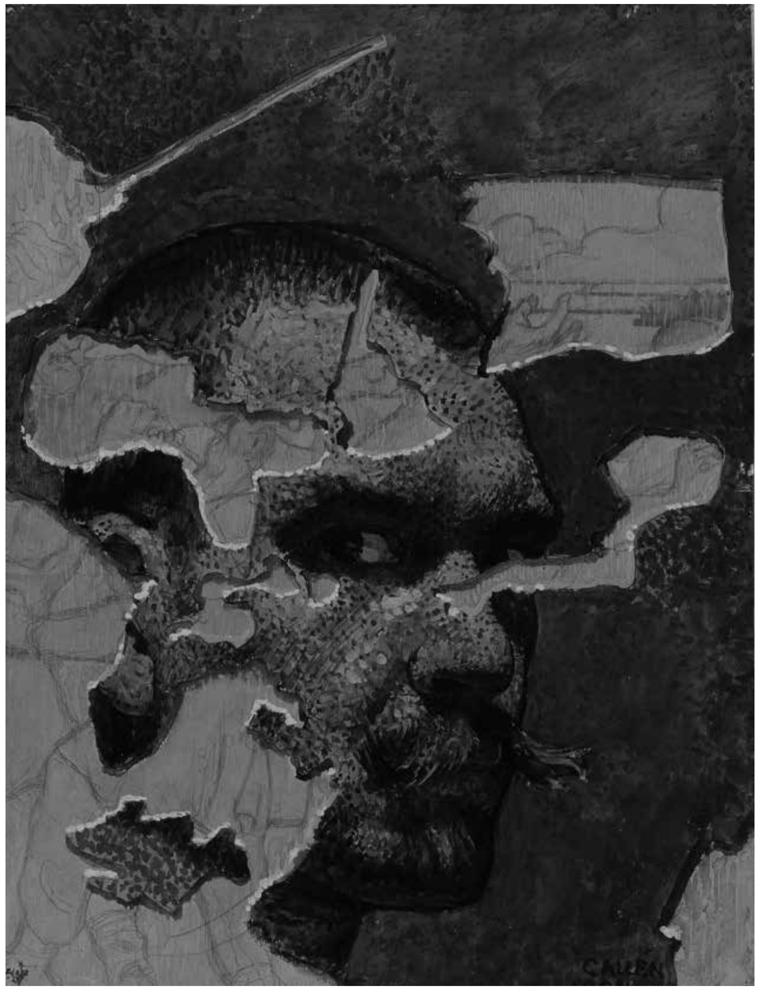


Fig. 5.10. Akseli Gallen-Kallela, self-portrait, 1894.

Helsinki, and is accessible by public transportation services. The architecture of the building itself is a mix of various styles including Finnish National Romanticism, Italian Renaissance, and various other Central European styles. The current museum was established in 1961. The museum has exhibition spaces comprising of 300 square meters. At the ground level are the main gallery areas: the artist's studio gallery

Fig. 5.11. Some of the ephemeral collections of GKM. Photograph by Anna Virtanen.

and the exhibition gallery. On the second floor and third floor are smaller galleries and pedagogy rooms.

GKM maintains an archive of ephemera such as postcards, receipts, stamps, tickets and photographs dating back to the Akseli Gallen-Kallela's 1920s associated with the contacts in the phonebook.[43] These are printed matter, small in size, measuring less than an A5-sized document (148 x 210 mm) and includes some handwritten items. Additionally, the archive contains ephemera such as greeting cards, postage, business cards, telephone records and manuscripts related to AGK's correspondence, that provide an alternative glimpse into the background of the artist's personal life and artistic practice. Although not monetarily evaluated or exhibited, this ephemeral collection could be considered significant as Finnish national cultural heritage from the early twentieth century.

By 2013, a small portion of AGK's paintings and works of art had been digitized and saved for long term preservation (in 2014, the museum had 7426 objects in its collections of which 3878 were digitized, and 13,508 photographs of which only 2453 were digitized, including some that can be browsed on the Google Art Project). Yet, the ephemera related to his communications with his circle of friends and acquaintances remained in the background and awaited a thorough and comprehensive digital examination. Much of it was stored away in the cellar of the museum and only a few representative items such as the phonebook and calling cards were intermittently displayed in the exhibition gallery. Some of the ephemera was also thought to be owned by the community members of the museum, but never displayed or exhibited in public. Although, GKM had aspired to digitize portions of these ephemera, due to limited funds and human resources, the museum had not been able to embark officially on a digitization program. As a result, the bulk of ephemeral heritage of AGK remained confined to the archive cellar and scattered among the museum community.

Between 2013 - 2014, we collaborated with GKM to explore digitization processes for the museum's ephemeral collections. Firstly, an open source scanning system was proposed to GKM. Then, an online digital archive was designed and built to house the museum's ephemera and community-donated heritage. Finally, community days were organized at the museum to gather and digitize heritage. Our process raised several questions regarding the research on the digitization of cultural heritage:

1. Can digitization be low-cost and be performed without substantial human resources?
2. Could open source software and hardware be utilized in place of proprietary equipment?
3. How can community participants be involved with the digitization process?
4. Could participation in the digitization process increase engagement with the museum's collections.?

We collaborated with Project Gado of Johns Hopkins University to reuse and develop their open source archival scanning robot which small archives can use to digitize their photographic collections. Since 2010, Project Gado has worked with the Afro American Newspapers to digitize, distribute and monetize their historical photo archives, which include 1.5 million photographs dating back to 1892.[44] In 2013, Getty Images agreed to license historic photographs digitized by Project Gado's technology to the media for use in print and online publishing.[45] In October 2015, Project Gado released over 1000 images into the Public Domain.[46] These images are from the mid 1890s to the late 1980s, and cover a wide variety of topics, from major historical events to nature, Americana, travel, and everyday life.

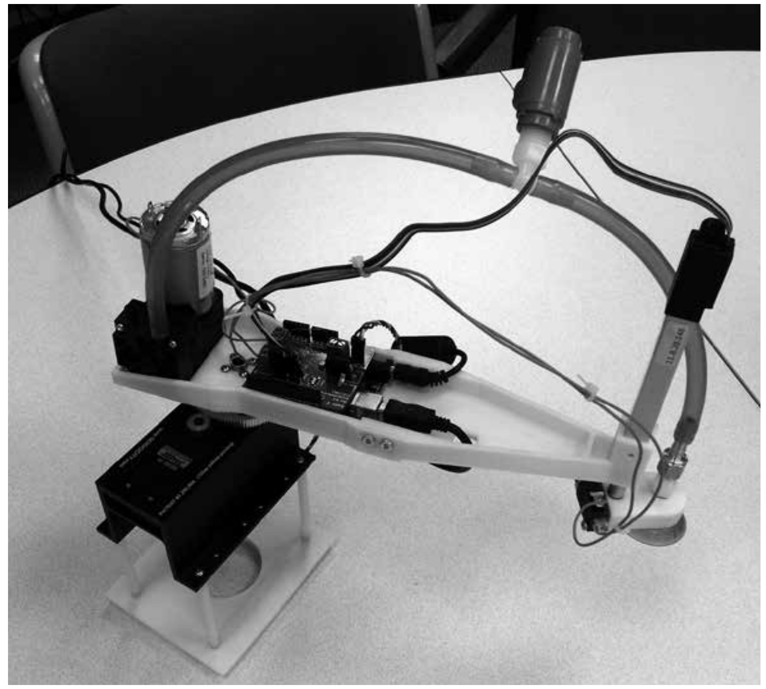


Fig. 5.12. The Gado 2 robot. Photograph courtesy of Project Gado.

We procured the Gado 2 kit (cost: ~550 USD) and developed it in our labs as an open source robotic scanning system that solves the need for a low-cost automated scanner. We forked Gado's open source software and customized it. Our system can be assembled and inexpensively fabricated without resorting to large-scale industrial machines. It has low energy consumption. The entire system is portable and can be rapidly deployed in remote museum locations. It is semi-autonomous, robotic-assisted and allows for the digitization of small (Paper size A5-A6) ephemera such as photos, postcards, index cards, letters etc. The total cost is under 1000 euros. The scanning system was then tested at the Gallen-Kallela Museum. Digitization of small print media items including some of the museum's archival collections and visitor-contributed items was studied over several days.

5.2.7 A NOTE ON EPHEMERA AND DIGITIZATION

Ephemera is a word often used in the field of Library and Information Science. It denotes a class of published single page documents that is of one-time use and may not be preserved or archived. This also includes letters, photographs and manuscripts. Libraries and Archives collect ephemera as heritage. They are often about singular events, correspondence, catalogs, price lists, bills, invoices and receipts. Historians from social, cultural, and business disciplines today recognize their value as source material. In context of art history, "ephemeral materials contribute to the study of an artist and their work, and how that artist was perceived in the context of the art scene…they generate a body of material that reveals a particular moment."[47]

According to Andrews, ephemera provides us with a very particular kind of evidence: "it offers an opportunity for scholarly analysis as well as a more subjective quality, an almost emotional and tactile response to worn and fingered material, directly handled by the people whose concerns and activities we are trying to understand, material that against the odds has survived and come down to us, often in a fragile state"[48] In this regard, Mussell says that, "the print objects that we regard as ephemeral are not supposed to survive," since they belong to the mass of things that we utilize, but necessarily forget. Yet, "it is this connection with the countless transient artefacts of everyday life that makes ephemera so valuable for historical research."[49] Every item of ephemera tells a story, or at the very least reveals specific information about something. In fact, ephemera tell us something even more specific than other printed material.[50] Thus, Mussell says that — "when we encounter printed ephemera, whether it survives by chance or design, we have a rare opportunity to engage with a component of the information economy that should have been lost."[51]

Ephemeral collections that have survived and have been digitized can be found on museum archives and online digital collections. Some examples are the Victorian Ephemera in the Manchester Metropolitan University Special Collections and the Mogens Otto Nielsen Mail Art Archive at the KUNSTEN Museum of Modern Art in Aalborg, Denmark.[52] These are typical instances of institutional digital archives of collected ephemera. Other museums such as the Cooper Hewitt Smithsonian Design Museum also host a limited quantity of digitized ephemera on the web from the field of decorative arts and design. These collections however tend to be located internally within the institution's practices and not open to the general public for participation.

Besides public institutions, organizations such as Historypin or Art UK facilitate the collection and tagging of historical material, some of which is ephemeral heritage, which otherwise would be forgotten and lost.[53] Here, the process is enhanced by participation of local communities via shared digital archives online. Another popular example is Flickr, an image hosting and sharing network that allows visual material searchable through crowd-sourced tagging.[54] Or for that matter Instagram, that could be utilized for uploading and sharing digital ephemera as part of a social network. These have provided social environments for the return of ephemera online. Yet, although these organizations and privately owned networks assist communities with digital tools and services, by hosting archives or by offering social media metrics and analytics, they do not necessarily provide guidance with digitization infrastructures. The digitization of historical ephemera is left to the remote contributor, who has limited knowledge of archival practices, does not own scanning equipment and in most cases not trained in the digitization of heritage.

OPERATIVE METHODOLOGIES 5.3

These are the methodologies that emerged during the design, construction and deployment of the design intervention. Some of these were brought forward from the earlier design intervention Light is History. We consider the dominant methodology used in this design intervention was Critical Remediation besides Critical Making, Community-Sourcing and Open Source. Microstructuring as a methodology was used in the design, planning and deployment of the design intervention. In the larger sense, the design intervention is – “a reading of old media and new media in parallel lines”. [55] Here the old media is repurposed within a new media system with enhanced functionalities, where the capabilities of the old media are not discarded. The design intervention also remediates heritage artifacts and their contemporary interpretations through our scanning system to a digital archive. Thus, through these, it simultaneously plays with the past and the present.

5.3.1 CRITICAL REMEDIATION

The representation of one medium in another is termed as Remediation and is a defining characteristic of new digital media.[56] According to Bolter and Grusin, new digital media remediates its predecessors in a variety of ways:

> *“1. Where an older media is highlighted and represented in digital form without apparent irony or critique; 2. Where new media ties to refashion the older medium or media entirely, while still marking the presence of the older media and therefore maintaining a sense of multiplicity or hypermediacy; and 3. Where the new medium remediates by trying to absorb the old medium entirely, so that the discontinuities between the two are minimized.”*

Our design intervention falls somewhere between the second and third type of remediation and this is apparent in the many critical and reflective acts of remediation that happen throughout the design intervention. Media in the form of an old scanner marks the presence of an older media, but then becomes part of a new media system without completely disappearing. Project Gado had been using a flat bed scanner with their system. Our design intervention hacked/reused an

Fig. 5.13. Old scanner embedded into a ‘new’ scanning system.

old scanner, the long standing standard device for digitization in libraries, archives and museums.

We embedded the scanner into our specially designed portable digitization platform and by adding a robot arm we repurposed it as

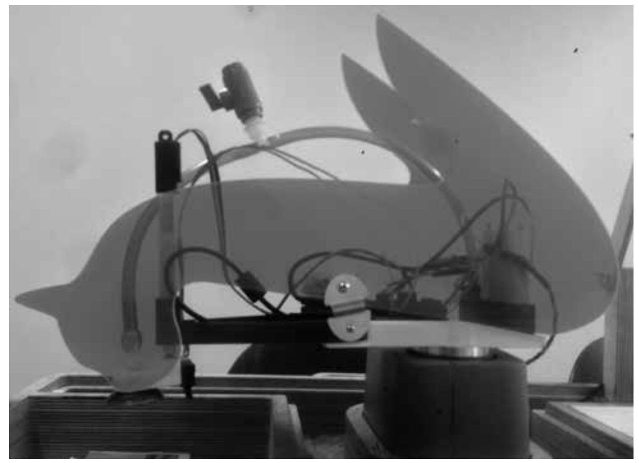


Fig. 5.14. A feline version of the robot arm being tested at the lab.

part of an automated digitization system. Although set deep into the deployment platform, the scanner does not disappear completely and is quite visible via the linear array of lights during the acts of scanning. It exists alongside the robot arm, the hi-definition camera and the input-output trays in – “a state of multiplicity and hypermediacy.”[57]

Process-wise, digitization activities that are part of an older (hidden and specialized activity) system associated with the scanner are also remediated and brought to the forefront of the museum. Our design intervention took the back office activities of the museum to the front gallery. It exposed hidden processes that usually occur in the invisible infrastructure of the museum. Here, the older methods of digitization are not completely erased but rather augmented by the robot automation and exposed to the presence of an audience.

The Haloo Akseli archive remediated a 1920s phonebook to a digital form. The original phonebook is a small printed medium in landscape format with a brick-red hardcover jacket. It has pages ordered by the Finnish alphabets that are exposed to the user for quick browsing.

Fig. 5.15. *Left*, Phonebook of Akseli Gallen-Kallela 1920s; *right*, an interface sketch of the new digital archive. Photograph by Anna Virtanen.

Several aspects of the design of the phonebook was carried over to the graphical user interface of the digital archive. The alphabetical ordering of the phonebook was implemented on the archive with its associated contacts and content. Each alphabet on the archive was allotted several contact profile pages with their own bank of clickable images, texts and links. All pages were tagged and linked with each other. The digital archive added several new functionalities that would have been impossible on the print medium, thus augmenting the design of the phonebook on the web. The older system of organization is still visible on the digital representation and as such exists in parallel and in hypermediacy.

CRITICAL MAKING 5.3.2

Our design intervention was conceived, designed and implemented in a critical ‘maker’ and reflective ‘DIY’ spirit.[58] It was concerned with making a new physical device assisted by electronics, robotics, 3D printing and CNC tools using open source and readily available off-the-shelf components. We repurposed a black-boxed media, the scanner, transforming it into a novel media artifact with new operations and processes.

As discussed in 4.3.2, the basic principles of Critical Making guided our project. Here we were engaged in design work that bridged the gap between both physical and conceptual exploration, the exploration of materials and material-based work that generated critical thinking.[59] There was a strong focus on ‘learning by doing’ in a collaborative networked team, i.e.. we gained detailed knowledge of scanning components, their actions and various print media through making and testing our device. Our work also lay at the intersection of traditional domains such as wood working, print media and emerging digital technologies.

The original Gado robot was a ‘maker’ project by Tom Smith of Project Gado. It grew out of the work he was doing as an undergraduate in the Anthropology Department, and for the Center for Africana Studies. He designed and built the robot in 2010 when he observed a lack of photos of the East Baltimore community, found that the Afro American Newspapers had a tremendous collection of historic photographs hidden away in its

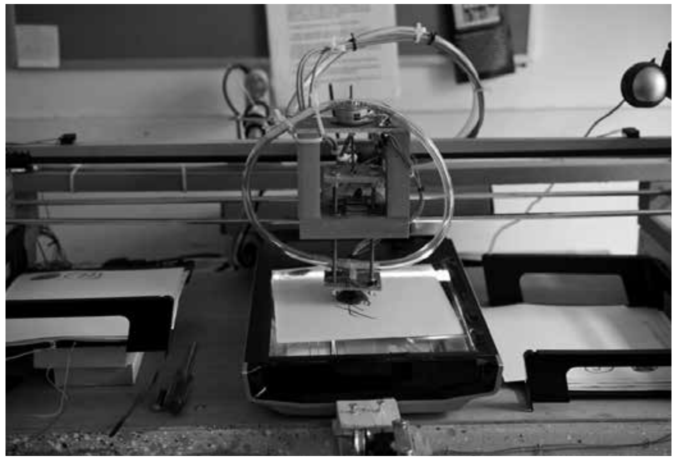


Fig. 5.16. Original Gado 1 robot at the African American Newspaper's Archive. Photograph courtesy of Project Gado.

archive, and realized the need for a new technology that organizations like the Afro could use to make their photo collections available to the community.[60] Smith brought together several low cost advanced hardware into a simple solution of an Arduino and Python based robot that used a suction lifter to lift sensitive archival photographs, place them on a flatbed scanner and autonomously digitize them.

For our remediation intervention, 'making' involved assembling the open source Gado parts, sketching designs for a new casing, 3d printing parts and testing iterations with various components of the robot arm. The building of the portable deployment platform was also part of the making process ie. from recycled plywood by a CNC laser cutting machine. We designed new covers and casings for the Gado robot arm to cover and protect the assemblage of wires, circuit boards, pump and servo motor. We 3D test printed them in pieces to understand how a new cover for the robot would affect its workings. For this we utilized a large format 3D printer.

We printed alternative arm bases for the robot arm using a smaller 3D printer: Ultimaker and its associated preparation software 'Cura' in the fabrication lab. [61]The drawings are in STL (stereolithography) format (widely used for 3D printing, rapid prototyping and computer

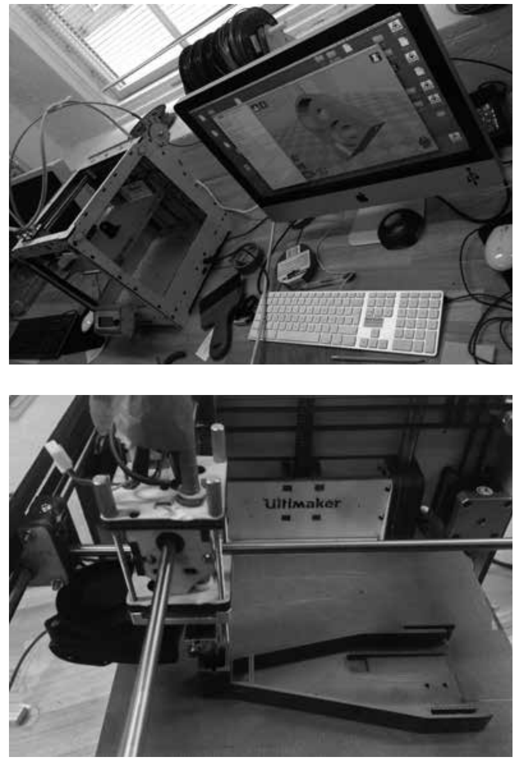


Fig. 5.17. 3D printing of the robot arm at the Fab Lab.

aided manufacturing) are available for download on the Project Gado Github repository.[62] We also experimented with printing multiple suction cup holders for the robot arm with variable attachment holes for the linear actuator.

By making and testing multiple iterations and manufacturing of the robot arm and the deployment platform we were able to learn more about the components themselves and their workings. By reflecting on the methods we used in our initial attempts at designing and printing, we later developed a more fluent process of design to testing to deployment. As such, the act of making, reflecting and learning went hand-in-hand throughout the duration of the intervention.

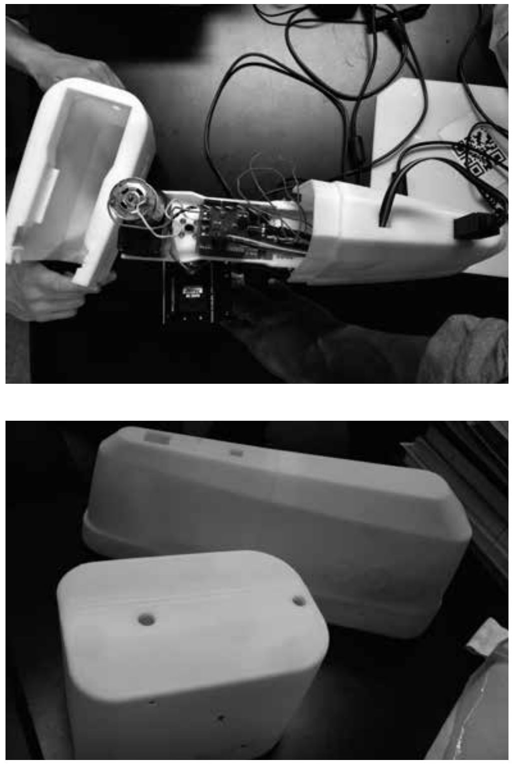


Fig. 5.18. 3D printed casing and base for the robot arm.

Fig. 5.19. Various Iterations of 3D printed suction cup holders at the Fab Lab.

OPEN SOURCE 5.3.3

"Open source software can and should therefore be seen as a legitimate and robust alternative to proprietary formats and software, offering, as they do, ever evolving solutions, supported by the wider stakeholder community."[63] Our intention was to build a low-cost portable digitization system for small museums and archives with limited funds and resources. As such, our design intervention has been mostly conceived through open source hardware and software (except for the proprietary TWAIN flatbed scanner).[64] Our automated digitization system is low-cost and can be assembled for under 700 euros which includes the cost of procuring the hardware components, the flatbed scanner, webcam and wood for CNC milling. The software and component schematics are freely available for download from GitHub.[65]

For our design intervention, we used the open source Project Gado as a base reference for the code that we expanded using Open Source libraries. As a result we created a new GNU/Linux application and tools so that users could interact with the digitization system. We released the original design of portable deployment platform under a Creative Commons license. During this process we were able to contribute back to Project Gado too. The code on GitHub is a contribution back to the Open Source community.

COMMUNITY SOURCING 5.3.4

Crowdsourcing has been described as – "the act of taking work once performed within an organization (such as a museum) and outsourcing it to the general public through an open call for participants."[66] In museums and cultural heritage, crowdsourcing – "asks the public to undertake tasks that cannot be done automatically, where the activity itself provides rewards for participation and contributed to a significant shared goal."[67] Crowdsourcing is more than merely a system for creating content through others. As a form of engagement with museum collections and memory institutions, it benefits both audiences and the institutions. Building a successful crowdsourcing project for a museum requires – "an understanding of motivations for initial and ongoing participation, tasks, content-validation, marketing and community building."[68]

Our crowdsourcing rather took the form of "community-sourcing" at the Gallen-Kallela Museum, in a sense that there was a known audience and community rather than an anonymous crowd involved. This community-sourcing was motivated by gathering audience participation through active contribution of artifacts for digitization. This was initiated during an exhibition opening and at successive significant events at the museum. For this we had to design the modalities of participation beforehand in agreement with the museum.

We designed and organized three Community theme days, starting from February 9, March 9 and April 26, 2014. The intention was to initiate community outreach, community-sourcing and engage the museum audience in the digitization process, i.e. to participate in the non-public activities of the museum. The main aims of these theme days were in themselves to test our designed infrastructures:

1. Whether the scanning robot was viable? (by allowing audience to utilize our digitization system in the scanning and tagging of their own historical materials).
2. Could the digital archive gather local communities and encourage their involvement with the digitization activities of the museum?
3. Could we initiate the sharing of audience stories and memories of relationships with Akseli Gallen-Kallela's artistic works, locations of his paintings, his friends and networks?
4. What were the factors involved in audience participation and whether it was possible to increment involvement?
5. Can we provide a platform that could in the future allow for remixing of the collections of the museum?

We designed and deployed media infrastructures such as the project blog, social media accounts for the museum that were needed for initializing the design intervention. The digital archive is the prime motivation for ongoing participation beyond the design intervention.

The primary tasks for participants were to contribute an artifact related to the artist Gallen-Kallela for digitization and uploading to the digital archive. We created copyright documents that were needed for contributed artifacts. Through these a contributor of an artifact was able to sign off on the licensing rights to a public domain license under creative commons. We assisted the participants in documenting and digitizing their artifacts. We also organized participation through daily workshops around the digitization platform.

MICROSTRUCTURING 5.3.5

All the various material and media infrastructures of this remediation design intervention are tactically micro-scaled and micro-staged to deal with microhistories. This happened in two areas: 1. Structure of the media archive: 2. Structure of the deployment platform and the scale of the digitization artifacts. Microstructuring also assisted in the management and delivery of the design intervention on schedule.

The archive is structured to be a microblog and was inspired by micro-blogging platforms. According to Tuan-Anh, micro-blogging causes an increased personal stake in online discussions and debates.[69] The archive deals with specific events and un-mapped activities i.e. micro-histories from the artist Akseli Gallen-Kallela's life to be charted and then linked to his network of artist friends and acquaintances. Dealing with micro packets of heritage allows – "increased participation from the museum audience, and participatory micro-history archives could effectively solicit community participation in the archival endeavor."[70] The structure also works well with linked open data, when micro packets of information from other archives are linked to it.

The deployment platform was designed to be portable and easily transportable and applies to small and remote museums without digitization infrastructures and dedicated personnel. As such the dimensions of the platform are also scaled to an appropriate size for a single user. This user could easily and quickly setup the platform and initiate scanning runs within a small space. The designated artifact size is similarly of A5 media size and the platform is only suited for small ephemera. This microstructuring of digitization allows curators to digitize and add micro packets of heritage (A5 sized digitized artifacts) on a daily basis to steadily expand the archive content.

Microstructuring the design intervention assisted and benefitted in managing it on several fronts. Since we were a collaborative team spread over two schools of science and arts and also including the curators and collection managers of Gallen-Kallela Museum itself, we had to organize the communications, research, making, programming and event planning on an efficient schedule. We had to scale work related to guidelines for participation, copyrights, benchmarks for artifacts and feedback processes. All of these had to be in a manageable time and format for our small team.

Microstructuring digitization projects is suitable to small museums and archives. It assists them when funds are scarce and trained personnel can be difficult to recruit. Microstructuring can also lead to a change in the scales of operations of a museum and provide alternatives for heritage conservation.

5.4 HARD MEDIA INFRASTRUCTURE

5.4.1 DIGITIZATION SYSTEM ASSEMBLY

The making of our digitization system infrastructure involved several stages of assembly, research and making in the lab. At first we imported the various components from Project Gado, and assembled the robot arm in-house. Secondly, we experimented with customizing the work area, robot arm, its movement and suction capabilities (testing with different print media) and the flat bed scanner. We also ported the user interface software from Windows to the Linux operating system. Finally we developed the portable deployment platform for the system through an industrial design competition.

The Gado 2 kit was in an early Beta stage. A complete instruction manual and working graphical Python-based application came with it. Users were recommended to do a little tinkering and or code tweaking; since it started as an open source project, a hands-on modification by the community was encouraged. Most of the components as part of the kit were standard industry off-the-shelf models, the hardware and accessories included screws, nuts, tie wrap, QR codes printed and tape. These are listed below:

Assembly of the robot arm was done in the following 10 steps

- Step 1: The Gado circuit board was attached on top of the Arduino microcontroller.
- Step 2: The two arm pieces were screwed together.
- Step 3: The assembled arm was placed onto the shaft of the servo base and attached.
- Step 4: The Linear actuator was inserted into the rectangular holder and attached.
- Step 5: The suction cup assembly was attached to the end of the linear actuator's metal shaft.
- Step 6: Plastic legs attached to the servo base.
- Step 7: Vacuum pump, tubing, valve and suction assembly connected.
- Step 8: Arduino & circuit board attached to the arm.
- Step 9: Wired up the servo, actuator, pump and pressure switch.
- Step 10: Wires and cables tied together to avoid interference with arm movement.

Additionally, we installed a flat bed color document scanner: a CanoScan LiDE 210 as part of the overall system. Our system infrastructure also included hardware such as a laptop computer, an extra Hi-Definition webcam, and dedicated power hubs.

We designed the work area for our digitization system based on the need for on site rapid and remote deployment, as shown in Figure 5.21. This was to generate preliminary specifications and dimensional requirements for a robot arm enclosure and a deployment platform. [71] From this, we identified several inputs and requirements for a new industrial design: The need for readily available stereolithographic (STL) design files for 3d printing the parts. We made a list of the major components (motors, pump, linear actuator, etc.) and composed a user guide.

Table 5.4. Components of the Gado 2 Scanning System *Scanner was not included in the kit.

MECHANICAL	ELECTRICAL	3D PRINTED PARTS
Base Motor	Arduino UNO Microcontroller	Rear Arm Piece
Vacuum Pump	Gado2 Circuit Board	Front Arm Piece
Tubing and Adjust Valve	USB Cable	Bottom Plate
Suction Cup Assembly	IPEVO Camera	Plastic Legs (4)
Linear Actuator	Power Supply	
Metal Cup Barb		

The new layout's arm length had to be of similar length as the existing. The height or diameter of the pump determined a max height / width for an arm enclosure. The weight of the platform could not be too much so as not to apply significant stress to the axle of the base motor. Free fluid movement in rotations of the robot arm was essential. The size of pieces was limited to the capabilities of 3D printers used in our labs. The cables were to be arranged without binding during rotations (causing abrasion). The attachment for the linear actuator

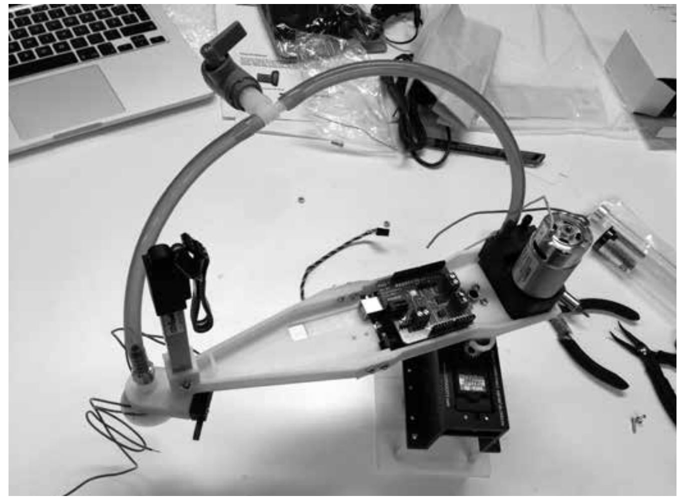


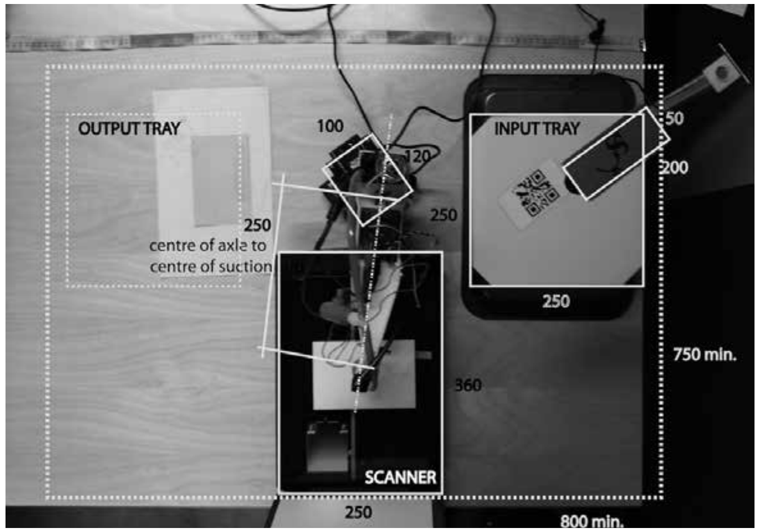
Fig. 5.20. Assembling the Gado 2 in the lab.

needed a better solution. Whether the bottom plate under the motor also needed to be re-designed (as part of a larger carrying box)? Manual access to the pressure valve to tune the pressure was also needed and for debugging, a window to see the Arduino's blinking lights.

PORTABLE DEPLOYMENT PLATFORM 5.4.2

The Industrial design of the deployment platform to our alpha system solved a majority of the requirements we identified in the preliminary system assembly. It offered the feasibility of remote deployment of a portable digitization lab, simplicity of use without the accompanying visual clutter and in a design sense where the act and process of the digitization itself was highlighted.

The portable deployment platform is a foldable carrying wood case that unfolds to become a digitization workstation. All of the platform's structural elements were realized using Computer Numerical Control (CNC) mills, 3D printing and fabrication facilities available to the design intervention. The casing of the robot can be 3D-printed and sound isolation fabric (for example 2mm thick) could be inserted and extra



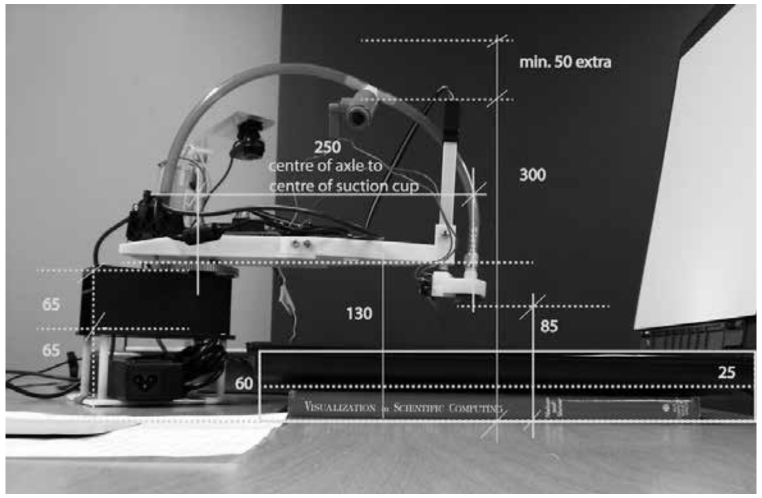


Fig. 5.21. *Top*, Preliminary layout of scanning system; *bottom*, Charting the movement of the robot arm.

space for the cables to move freely (the plastic parts of the robot were modified and 3D-printed from openly available design files available on Project Gado's Github code-sharing repository). The platform itself is made from recycled plywood by a CNC laser cutting machine. The platform is foldable into single portable carrying case. Within, spaces are allotted for input tray, output tray and scanner device. Under a removable cover are the cables and adapters hidden from view. The heights of the input tray and the scanner are adjustable by adding or subtracting the layers plywood. The camera stand folds out and can be removed and packed for transportation. The scanner can also be placed in a cushioned compartment. The robot arm itself needs to be stored away in its own traveling kit.

The entire deployment platform currently consists of a Gado Robot arm, two powered USB hubs, one Logitech 2mp autofocus webcam, one CanoScan LiDE 210 digital document scanner from Canon Inc. and a deployment platform to house, stage and efficiently transport the entire system (robot, scanner, webcam and cables) for use at various locations. Figure 5.22. shows the designed system. Additionally, a laptop computer is also part of the system that manages the digitization process through a custom designed user interface. Table 5.5. shows specifications of the system.

The portable deployment platform makes it low effort to consistently deploy the robot in new locations with a known floor area. It fixes the location and height of the robot, the input and output trays and the document scanner to known unvarying values. This simplifies the implementation, deployment and use of the overall system. The hardware design files are licensed Creative Commons BY-SA 3.0, that allows copying and redistribution of the material in any medium or format, and can be remixed, transformed, and built upon for any purpose, even commercially.[72]

ROBOT ARM 5.4.3

Our digitization system's primary functional meta-component is the robot arm. It includes the linear actuator, suction cup assembly, the vacuum pump, tubing, adjusting valve, Arduino microcontroller, Gado circuit board and the servo motor. The linear actuator is a linear motor used for moving the suction assembly; the suction cup made of rubber

Fig. 5.22. *Top*, portable deployment platform; *bottom*, robot arm carrying case. Illustration by Verna Kaipainen, distributed under CC BY SA-3.0 license.

creates negative air pressure, a partial vacuum to attach itself to a media; a switch attached to the suction assembly indicates when the suction cup is touching the media; the vacuum pump removes air from within the attached tubing and the suction cup; one can regulate the

Fig. 5.23. The fabricated portable deployment platform.

suction pressure using the adjusting valve; The Arduino microcontroller along with the Gado circuit board controls the robot's rotation, linear actuator and vacuum pump and finally the Servo motor that rotates the whole arm assembly. Together they perform the act of autonomous movement as directed by our program.

The laptop computer controls the digitization process by communicating with the Arduino microcontroller on the robot. The role of the webcam is to detect a Quick Response (QR) code permanently affixed to the bottom of the input tray, that indicates to the digitization computer when the input tray's stack of photos is loaded and scanning can begin or stop. It can also be used to take a picture of the face-up side of the item on the tray (currently the webcam takes images that are 640 x

Table 5.5. System Specifications

DIMENSIONS	1000 x 800
WEIGHT	Workstation: 5 Kilos; Carrying Case: 3 Kilos
SCANNING RESOLUTION	150/300/600 dpi
POWER SOURCES	(i) Robot: AC power adapter for vacuum pump + powered USB hub for Arduino and actuators, (ii) Scanner: own AC power adapter + powered USB hub (shared with webcam), (iii) Laptop's own AC power adapter

480 pixels, which may be sufficient for documentation purposes). The robot arm has a fixed length and rotates from zero degrees (input tray) to 180 degrees (output tray). At the end of the robot's arm is a linear actuator with a vacuum cup. The height of the vacuum cup can be varied from 0 to 120 mm (maximum) downwards onto the top item in a stack of printed items.

A depressed actuator switch indicates when the vacuum cup is on top of an item to be picked, and then the vacuum pump is enabled with tuned vacuum pressure (for the material type) to pick up each individual item. The linear actuator is then raised, and the arm is rotated and translated to place the object onto the document scanner for scanning. An A4-sized flatbed document scanner is used to take a picture of the facedown side of the item (resulting images are 3543 pixels long by 2556 pixels wide, at a resolution of 300 pixels per inch). The scanner is located at a fixed rotational angle and height. After scanning the robot arm is then raised and rotated over the output tray where the vacuum is turned off to deposit scanned items. As a troubleshooting option, a test program, ie. Python test script was also developed to individually test each the robot's main functions: e.g. vacuum pump on/off, rotating the robot arm, extending the arm, etc. This is an essential step to test the robot's setup, before using it for scanning runs at any new deployment.

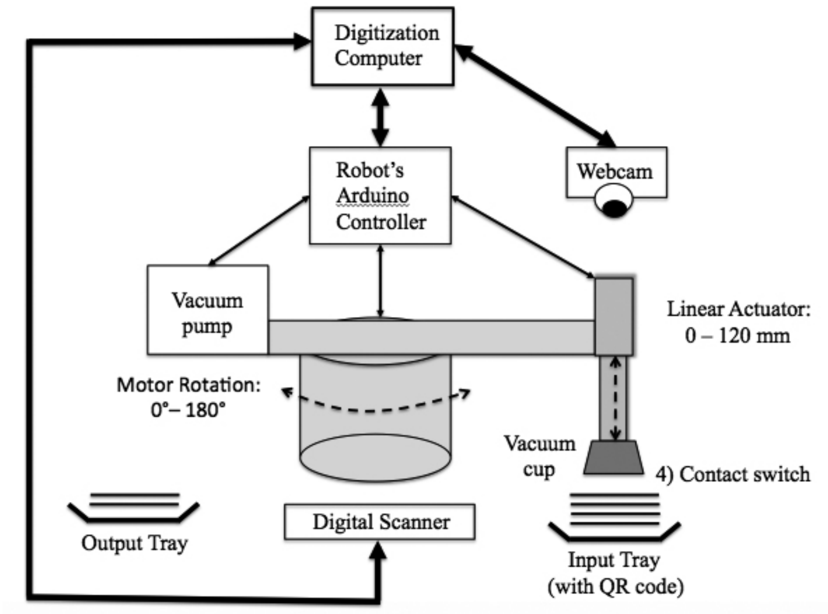


Fig. 5.24. A System overview of the robot arm. Illustration by James Reilly and Agusti Pellicer.[73]

IMAGE SCANNER 5.4.4

The off-the-shelf scanner is a proprietary black box and its inner workings are concealed. For our project we had to repurpose a generic flatbed scanner. The Gado has been designed to work with any off-the-shelf TWAIN-compatible flatbed scanner. TWAIN is a standard software protocol and API (application programming interface) for communication between software applications and image acquisition devices. So the quality of the scanning depends on the scanner chosen. However our goal was to extract a hi-resolution scan by using our own in-house developed software.

We chose a typical CIS flatbed image scanner CanoScan Lide 210 to perform the scanning tasks.[74] Its compact size and weight allowed the portable platform to be easily carried and deployable, and it satisfied our criteria for using the least amount of energy. However as we discovered, the scanning capabilities were limited in terms of resolution and archival quality. Driver issues also created robot initialization problems and compatibility issues with the Linux operating system.

The CanoScan is a CIS (Contact Image Sensor) based scanner. The scanning consists of a moving set of red, green and blue LEDs strobed for illumination and a connected monochromatic photodiode array under a rod lens array for light collection. Images to be scanned are placed face down on the glass, an opaque cover is lowered over it to exclude ambient light, and the sensor array and light source move across the pane, reading the entire area. An image is therefore visible to the detector only because of the light it reflects.

This CIS scanner consumes less than a tenth of the electricity used by other CCD-based systems. It uses small, lightweight and power efficient LEDs as the light source. It illuminates the document evenly with less power the entire width of the document evenly. The intensity does not change when the images are partially lifted and neither any discoloration take place due to the illumination. Not only does this represent an environmental benefit, it also plays a major role in enabling USB bus powered scanners that do not require an AC power source. Additionally, the scanning component is 1/10 - 1/20 the size of CCD-based components.[75]

As will be discussed in 5.5.1., we forked Project Gado's existing Linux source code and refactored it for the purposes of this design intervention. We used Standard Linux libraries for the scanner and implemented the code for scanning using an existing Python interface to the Linux SANE "Scanning is Now Easy" library.

Furthermore, we did a user study of the scanner in relation to the robot arm and suction power by conducting testing of various media. We timed how long it took for the scanner to complete a scan, how long it took to warm up, and whether it faltered during or between scans. Since it did not have an automatic document feeders, we placed each image/ document by hand and experimented the automatic and professional mode (the latter which generally allows more manual control). For text documents, when possible we also ran the scans through OCR (optical character recognition) software that came with the device. That software reads the text and saves it in a way that can be searched and edited.

Fig. 5.25. The scanner used for the scanning system.

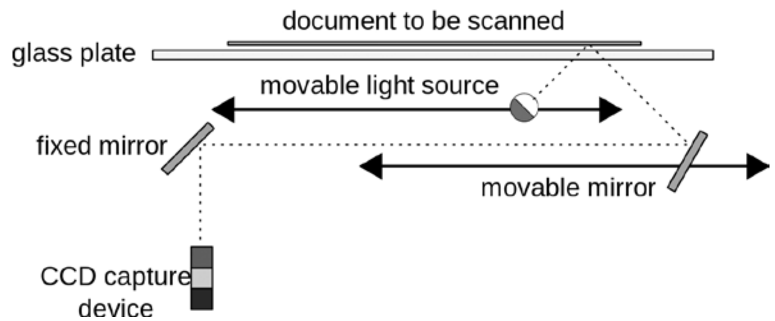


Fig. 5.26. The workings of a flatbed scanner. Illustration adapted from Jean-no, distributed under the terms of Free Art License.

Paper media characteristics such as bursting strength, compressibility, hardness, stiffness, surface strength, tearing resistance and especially resiliency are considerations for our scanning system. Material properties of paper may vary in the production, storage, printing and use of paper.[76] Low levels of vacuum pressure may need to be applied for certain types of paper materials, so that the media maintains its original shape during and after picking. The media should be low in weight, porosity and be relatively stiff. Small holes or cracks in an item may cause multiple items to be gathered when vacuum-based picking is used. Variations in media require fine-tuning the amount of vacuum pressure applied.

Table 5.6. Specifications of the Flatbed scanner

Max. Resolutions Optical	4800 dpi x 4800 dpi
Max. Resolutions Interpolated	19,200 x 19,200 dpi
Scanning Mode Color	48-bit internal / 48- or 24-bit external
Scanning Mode Grayscale	16-bit input / 8-bit external
Scanning element	Contact Image Sensor (CIS)
Light source	Three-color (RGB) LEDs
Max. Document size	A4
Dimensions (W x D x H)	9.9" (W) x 14.4" (D) x 1.6" (H)
Interface	Hi-Speed USB
Weight	3.4 lbs.
Power Source	Hi-Speed USB
Max. Power Consumption	2.5W (1.4W Standby)

Thinness or low opacity of an artifact affects a scanned image (see 5.6.7. Unresolved Technical Issues). Very thin media with low opacity could have a shadow of the robot arm's vacuum cup visible in their scan. It is because the scanner shines a bright light from underneath the item during a scan. This issue is most evident in modern photos or very thin postcards. Older photos especially from the late 1890's or early 1900's are easier to handle since they can be quite thick (around 1 mm).

The size of the artifact is crucial to the system. Sometimes, there is a certain degree of variation in the rotation of the artifact when it is picked up by the robot, and subsequently rotated and placed onto the scanner. That may cause unwanted cropping for larger artifacts that need precise alignment for scanning. Items larger than postcards or photos that are not made from stiff material usually droop at the corners when they were picked. Because such drooping items might possibly be damaged when the robot arm rotates over the scanner and deployment platform, such materials were not used in our studies.

ENERGY TRACKING HARDWARE 5.4.5

We measured the energy consumed by the robotic assisted digital scanning of artifacts. The measurement setup is shown in Figure 3. Four Plugwise Circle Energy meters manufactured by Plugwise BW of the Netherlands was used in the process.[77]

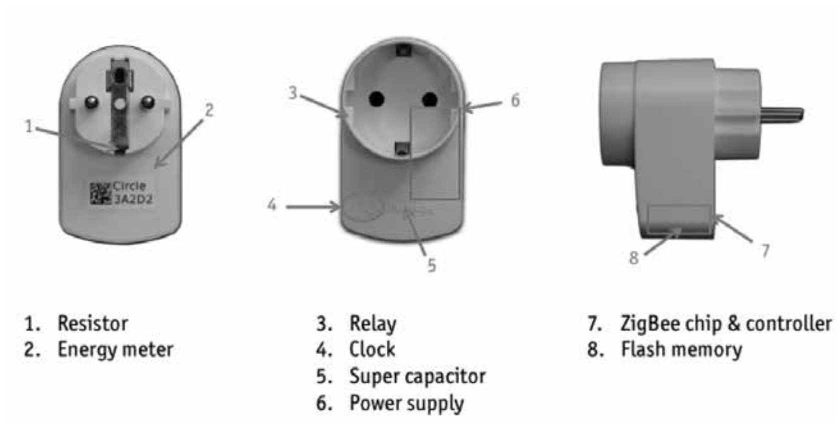


Fig. 5.27. The Plugwise socket plug. Photograph courtesy of Plugwise BV.

The Circle energy meter is a socket plug (socket type F) that can be plugged into any electrical socket, and that then allows other devices to be connected to it. One can control all the plugs from a central interface, switch on and completely switch off (allows remote control via its on-off breaker in the device). The Plugwise system, as a wireless energy management system does not require extensive cabling and works independently from energy providers. The system is portable and can be conveniently transported. In addition, the system has smart switching techniques which integrates energy savings and the user's needs. A designed interface, the Plugwise App on a tablet, smartphone or via the Plugwise pc software allows one to view the energy analytics.

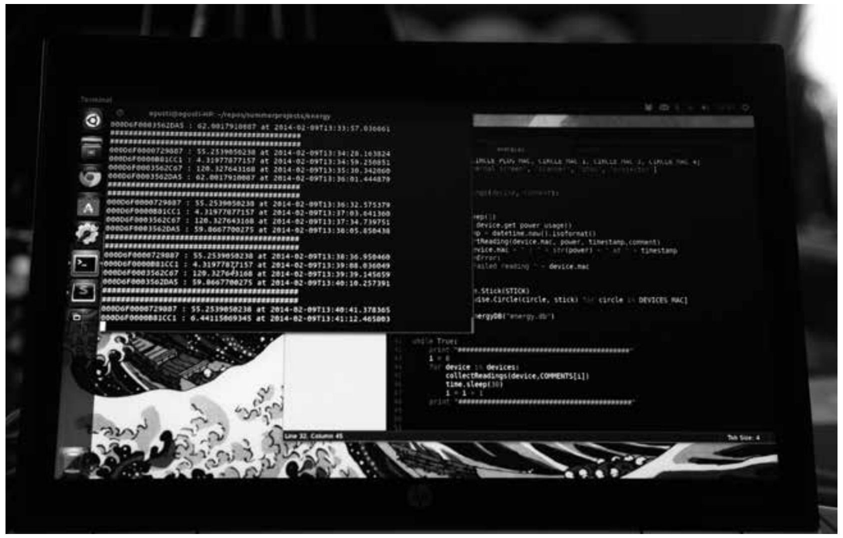


Fig. 5.28. Power measurements in progress at GKM.

The Plugwise measured AC electric power at several points of interest: 1) Total energy consumption, 2) Digitation computer, 3) robot + its powered USB hub and 4) a document scanner and a webcam powered via a second powered USB hub. Note that in the following sections, it was assumed that the loss at the power strips (kept as short as possible) and at the energy measurement units was negligible. The energy tracking analysis is explored in-depth in the Infrastructural Analysis section 5.7.

SOFT MEDIA INFRASTRUCTURE 5.5

SYSTEM USER INTERFACE 5.5.1

Project Gado's existing Linux source code was refactored for the purposes of this design intervention, and a new user interface was developed based on that. Standard Linux libraries were used for the webcam and scanner. The refactored code for scanning was implemented using an existing Python interface to the Linux SANE "Scanning is Now Easy" library. A multi-threaded Python application, serving as the User Interface (UI) for the robot was built on top of the Linux code for scanning a stack of photos, tagging them and saving them into a local database. The UI code controls the scanning runs performed by the Gado robot. Multiple items can be scanned per run, and image artifacts are saved to a local database. The modified source code was contributed back to Project Gado's public software repository.[78] The design intervention's UI software for the robot is also available as open source.[79]

The original Gado UI suffers from concision. There are too many buttons to decide from, all in the same font size hierarchy, and as such leads to user indecision and tedious to use. In the Gado UI, one could create a new artifact set, start, pause, stop and reset the robot all placed in the same zone. However, two side by side panels displaying the webcam image and the scanner image allowed for a review of the results, although delayed by the size of the image scan. For the participative nature of our design intervention, there was no way to tag the scanned images, nor to modify them.

In our Python application, we streamlined the UI and made it visually minimal, responsive and concise. One could start the process with choosing a directory and then already start tagging the artifact before scanning. Our UI allows users to tag their scanning runs, or to tag individual artifacts within a run, with text strings to describe them. Thus a non-technical user of the robot can initiate a scanning session using the scanning system and can textually tag their artifacts and runs. One could also choose from a ready database of tags, which in themselves

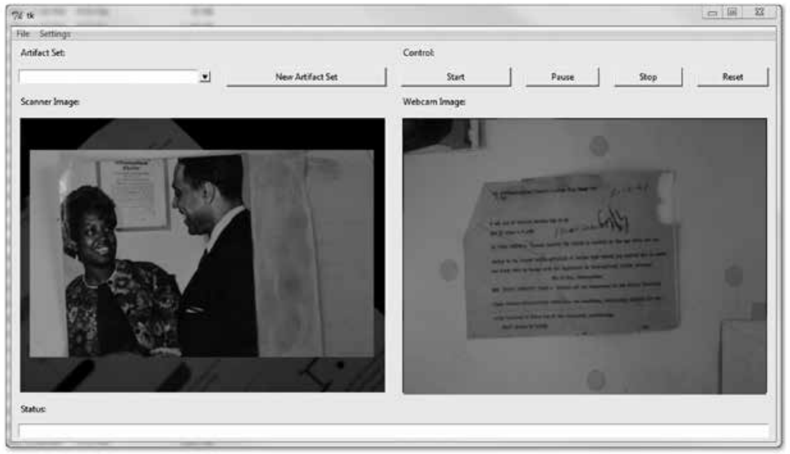


Fig. 5.29. User Interface of Gado. Photo courtesy of Project Gado.

could be imported from the original metadata of the museum's collections. After the scanning was completed, a fast loading thumbnail appeared to allow a quick review of the results. At this point one could further modify tags and continue scanning.

5.5.2 PYTHON APPLICATION FOR ENERGY TRACKING AND TESTING

An open source Python library called 'plugwise-python' was used for the energy measurements.[80] An existing Python library/code was developed to read the Plugwise energy monitors and store energy consumption readings to an SQL database.[81]

We measured the different components of the system and also the total energy consumption. We separated our system in the following parts: the laptop, the robot (including the power source and the USB hub), the scanner and webcam (including the USB hub) and then the total of the previous components. The official Plugwise application has limitations. The minimum granularity it displays of the energy consumption is for one hour and that energy data cannot be exported to

Fig. 5.30. *Top*, User Interface of the scanning system; *bottom*, scan preview and tagging, choosing tags from a ready directory.

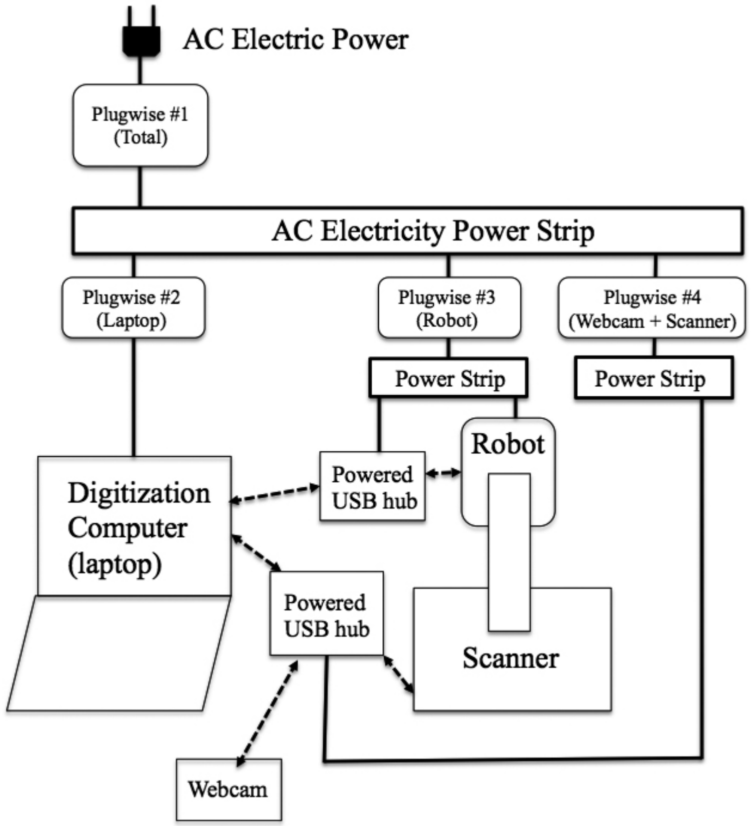


Fig. 5.31. Final setup used for energy measurements. The setup for taking energy measurement readings was refined over the three theme days. Illustration by James Reilly and Agusti Pellicer.[82]

other formats. We attempted to run the application in Mac OS X, but to interact with Circle+ it was required to install a VCP (virtual communications port) driver.[83]

As such, we used the python- plugwise, an open-source program on Linux, that let us poll more often the Circle+ device and be more flexible on how to handle the data. The tool is flexible and allows one to query the Circle+ for the various data that it collects. We used the following command to run our experiments: plugwise_util -d /dev/tty.usbserial-A700dr5f -m <MAC> -p -q time -c 2. The command prints every two seconds the power usage and the time.

DIGITAL ARCHIVE 5.5.3

We designed and implemented a digital archive Haloo Akseli based on Akseli Gallen-Kallela's 1920s phonebook that contains information about his artist friends, colleagues and acquaintances. The goal of the archive was to provide a repository for the digitized collections of the museum and its community, based around the items and contacts in the phonebook. This allowed specific events and activities from the artist's life to be charted and then linked to his network of artist friends and acquaintances. From this source, Gallen-Kallela's social network was mapped onto the digital archive. The archive was intended to attract users who could upload their or others' work related to Gallen-Kallela and his network. Thus the archive could serve as a fertile soil, for new heritage that was not currently present in the museum collections but resided in the community.

There are currently, 45 'Personas': Gallen-Kallela's friends mapped on the archive. Persona is usually the term for a role or a character. Personas are used in User Experience Design, where fictitious characters are used to help solve design questions.[84] In Haloo Akseli, Akseli Gallen-Kallela's friends are proposed as Personas. Each of the "Persona" are assigned with their own 'homepage' that hosts archival material related to them and Gallen-Kallela.

The pages reflect the artist's and his friend's lives, art and inspirations from the 1920s. The homepage may contain a wide variety of ephemera ranging from letters, photographs, quotes and links. All the Personas are interlinked, and some contain overlapping material. In the future, it is expected that, every Persona develops over time and contributes to the overall design and structure of the archive through the steady addition of heritage material. The personas will also thus, become intensively linked to Gallen-Kallela and others in the network producing an alternative life history.

The design of the archive was inspired by micro-blogging platforms. As already mentioned in 5.3, we examined studies in modeling

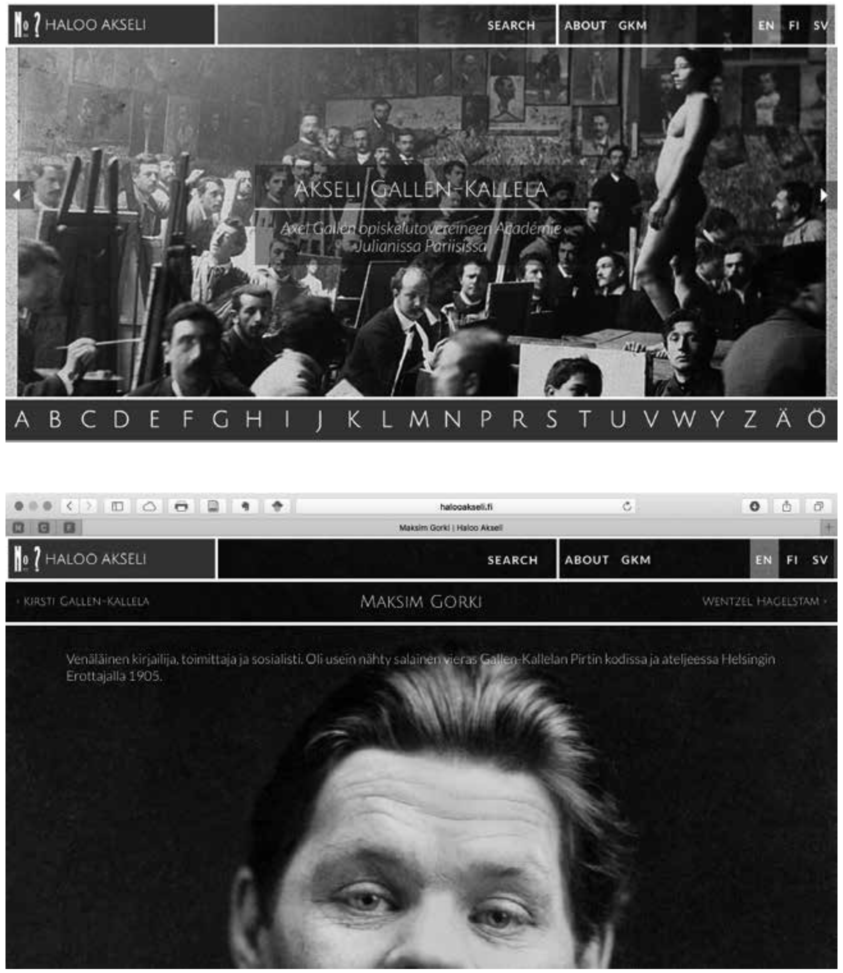


Fig. 5.32. *Top,* The interface of the Haloo Akseli digital archive; *bottom*, the Persona of Maxim Gorky in the Haloo Akseli digital archive.

community behavior and micro-blogging that show – “users via micro-blogging in their respective communities of interest have an increased personal stake in the online discussions and debates.”[85] Since, micro components of heritage allows increased participation from user communities, can “such participatory micro-history archives

Fig. 5.33. Some of the Personas of the Haloo Akseli archive: Albert Paul, Albert Edelfelt, Eric Bucklan, Maxim Gorky, Jean Sibelius, Eero Järnefelt, Louis Sparre, Akseli Gallen-Kallela, Ida Aalberg, Erik Wikström, Ville Vallgren, Mary Gallen, I.K. Inha, Siri Von Essen, Albert Engström.

could effectively solicit community participation in the archival endeavor.?"[86] Could our archive allow curators to digitize and add micro packets of ephemeral heritage (A5 sized digitized artifacts) to steadily expand the archive content? The museum's communities may also supplement the archive with their own heritage. This dual approach allows specific events and un-mapped activities i.e. micro-histories from the artist's life to be charted and then linked to his network of artist friends and acquaintances.

Fig. 5.34. The digital archive was designed to be mobile responsive.

As mentioned earlier, GKM maintains a physical archive in the form of ephemera such as letters, postcards, receipts, stamps, tickets and photographs that are associated with the Personas. Our aim was to digitize this ephemera and place them in the archive under a Creative Commons CC-0 1.0 License.[87] Here, the digitized ephemera of the various online Personas would serve as units of micro-history. Each unit uploaded to the archive would be considered as a micro-history of the artist and his network. The design of the archive is also based on the assumption that smaller pieces of heritage and information can work well with participation from smaller user communities.

5.5.4 COLLECTIONS MANAGEMENT INFRASTRUCTURE

The backend infrastructure of our digital archive is a collections management system based on Drupal, a framework written in PHP(Hypertext Preprocessor) programming language. For our design intervention, we scaled down its features to suit the small size and specificity of the ephemeral collections of the museum. An easy to use interface for adding collections and metadata by the museum was also constructed.

We studied an iteration of Drupal: CollectionSpace and developed our backend based on this. CollectionSpace has been built on top of the Drupal system and is used by several cultural organizations like the Walker Arts Center, New York and the Statens Museum for Kunst, Copenhagen. It allows for easy and efficient management of the digital assets of the museum through a user friendly backend. It is made, used and supported by a large online community. Its use and applications are versatile and numerous in the culture sector. The core Drupal code base is being actively developed and well-managed in the development community, and many plug-in modules are readily available.[88]

During the design process, we conducted a user study of the CMS with the curators and collection managers of the Gallen-Kallela Museum. Based on this we simplified the login, customized the metadata fields and inputs; we reduced the preferences settings and designed a concise UI to add new artifacts. The 'Create Artifact' function was the primary artifact management within the UI. There one could start by naming an artifact, then choosing an artifact type. We assigned several typologies based on the collections of the museum: letter, object, painting, photograph, postcard and sculpture. Tags were then added for each artifact to build a taxonomy for the collection. Each artifact was then assigned to a Persona or several Personas. Other metadata included dates, description, dimensions, provenance, use, acquisition, source, people involved and an extra field for a special entry.

Earlier the museum did not use a web-based collections management system and it was not possible to share the collections to the social networks. Now, the digital archive started to function as one of the main parts of the collections strategy. New content from the community was added to the archive with the necessary metadata as per archival standards. This content was then shared onto the museum's social media. Thus, through the web design implementation, our collections management infrastructure for the design intervention aimed to create an online, lightweight and versatile in-house collections management system for the museum and also as the backend for the public digital archive.

5.5.5 INFRASTRUCTURES FOR ENROLLMENT AND PARTICIPATION

How to gather communities (crowdsource) to a remediation project within a museum that demands active contribution of artifacts? How to organize participation in digitization activities that are usually the non-public activities of the museum? What copyright documents are needed for contributed art works in an art museum? What media infrastructures are needed for initializing a participatory design intervention within a small art museum?

The exhibition galleries of the Gallen-Kallela Museum along with the external premises served as the venue for the community events. During this time, participation-donation forms with copyrights information was composed for the community participants. These facilitated the submission of small heritage items and personal stories based around Gallen-Kallela. We also investigated into the use of a Creative Commons (CC) license. Our goal for the design intervention was that it should be open access and that participant-donated artifacts can be accessed unrestricted.

We also designed scanning/sketching cards for the third community installation theme day. The audience here was provided with special A5 sized printed card sheets that also served as their canvas. This card was designed to be handled by the autonomous scanning robot. The back of the card contained copyrights information related to the Creative Commons (see Appendix).

We researched and designed several mixed-media methods to kickstart the design intervention that included a project blog, Face-

Fig. 5.35. Artifact submission forms.

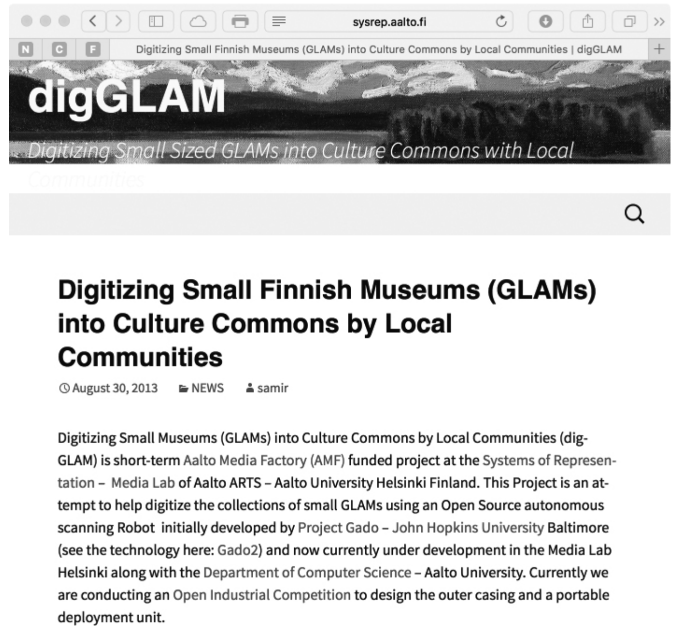


Fig. 5.36. Website for the design intervention.

book page dedicated to the artist Akseli Gallen-Kallela, traditional media announcements, the museum's own homepage and copyright forms for artifact contribution.

We built a Wordpress website for the design intervention. Here we started documenting the various experiments, communities and actions leading up to the actual theme days. The industrial design was posted along with images and workings of the portable deployment platform. Initial presentations were uploaded here and the announcements posted to the local communities of the museum and the university. The Community Theme Day Installations and panel discussions were also documented here. The Gallen-Kallela Museum announced the design intervention on its own website. They published advertisements on the traditional media such as the local national newspaper: Helsingin Sanomat. The museum also contacted their dedicated user communities related to the artist and his artist friends from the communities of Leppavaara in Espoo and Tuusula in Vantaa region.

We utilized social networks such as Facebook & Instagram to promote the design intervention and foster an online audience. The Systems of Representation research group as well as the museum (Akseli Gallen-Kallela himself has a Page dedicated to his life and works) advertised the community theme days on their respective Facebook Pages. We regularly posted status updates about the design intervention, artifacts and outcomes. The total reach was 127 members on the research group Page and 1776 members on the museum Page on the days before the community theme days. We also registered a new Instagram (an instant photo-sharing social network) account for the museum for the purposes of the design intervention. By posting on Instagram, artifacts or objects related to the museum and its collections, a person could gain free entrance to the museum events.

Thus, in the initial stage, through various new media such as online blogging platforms, social networks and even traditional media we reached out to new audiences and the user communities of the museum for our design intervention. In the installation stage, we used a combination of online media to propagate and generate community participation for the design intervention. We also utilized traditional printed media during the events in the form of copyright forms and scanning cards.

TRIALS, INSTALLATION & FEEDBACK 5.6

ROBOT ARM TRIALS 5.6.1

To solicit prospective industrial designers to develop solutions for the portable deployment platform, we conducted open events to introduce our digitization system. In the first open day, we organized discussions with the project team and viewing of the robot arm within the University's computer science community. We conducted trial digitization runs with a preliminary layout of the system (as shown in figure 5.29) and experimented with the scanning of various print media such as old documents and cards. Our system consistently failed to work with old A4 sized soft papers with high porosity levels. Thus we could not test the museum's fragile heritage items with our system due to possibility of permanent damage. It became apparent from our testing that our system could not handle thin printed media and that only papers over 160 grams could be reliably scanned.

In the second open event at the University's Design Department we continued with the demonstration of our digitization system to industrial design students. We experimented with old and new postcards,

Fig. 5.37. Demonstration of the scanning system.

museum archival index cards and other thicker papers. The outcomes of the scanning runs were more successful than in the previous open day. We developed a range of possible print media in terms of size and thickness that could be effectively scanned using our system. The scanning demonstration attracted design students and instructors who were informed about our design intervention, given specifications of the system and offered a scope for an industrial design solution.

Finally, in the third demonstration within the Media Lab community on Spring Demo Day, we tested the freshly constructed portable deployment platform. Several digitization runs were performed using the platform with postcards, photographs and small business cards. The user interface for the robot was also finalized and deployed.

5.6.2 COMMUNITY THEME DAY I: PARTICIPATORY DIGITIZATION

Our scanning system was first deployed publicly at the Gallen-Kallela Museum during the organized community theme days. On the first theme day, digitization workshops were synchronized with an opening of GKM's exhibition about Akseli Gallen-Kallela's paintings of the lake Keitele Kuinka Monta Keitelettä? (How many Keiteles?). These

Fig. 5.38. Digitization Workshop on Community Theme Day I.

workshops were held in the exhibition galleries where the community's archival material was gathered. The digital archive was also launched to start the documentation of community contributed artifacts.

The exhibition presented the artist's work through a number of photo-subjects and presented the digitization research done at the museum. It displayed the artist's multiple roles within his family, whose members serve not only as models, but also in the works and construction of artifacts. The audience on this day were the artist communities from Leppävaara and Tarvaspää in Espoo. They donated archival material related to the exhibition for digitization: old images pertaining to Akseli Gallen-Kallela and his artist-friends.

STUDIO GALLERY DAY 1

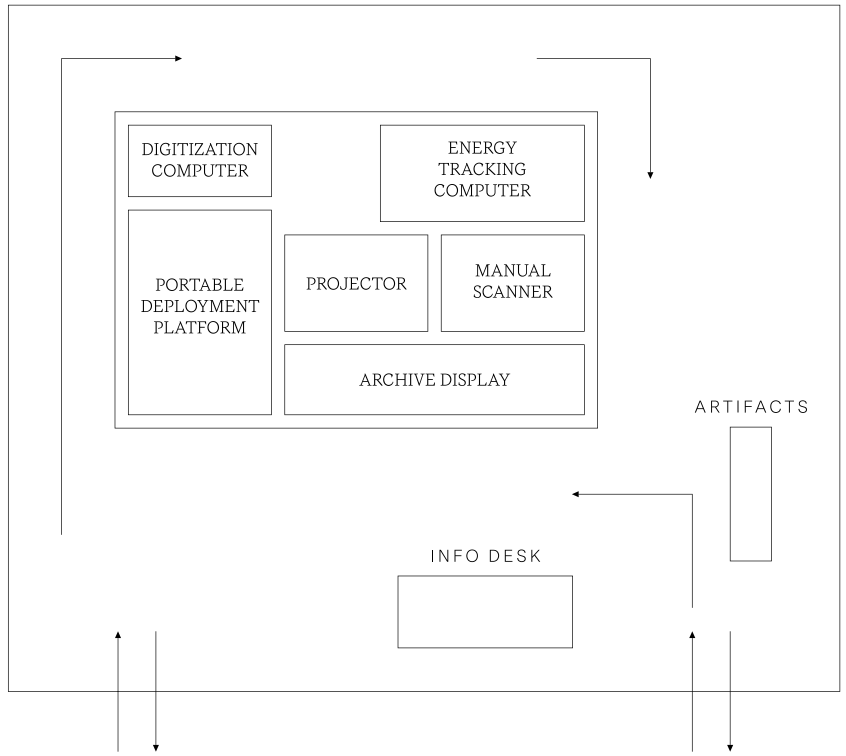


Fig. 5.39. Layout of the Digitization Workshop in the Studio Gallery on Day I.

A designated area in the studio gallery of the artist was set aside for the digitization workshop. Our digitization station consisted of the scanning system, computers to access the user interface of the robot and monitors to browse the digital archive. A manual scanner was also placed nearby to back-up the scanning tasks. Several computers were installed around the exhibition galleries for browsing of the digital archive. The community was instructed in the methods of providing new digital archival material. Our participation forms that included copyrights declarations were utilized by the community to submit their heritage items and personal stories. Donors of the artifacts were then assisted in using our digitizing system to scan their artifacts. They were guided to use the robot interface, start new digitization workflows, tag their artifacts and run the scanning process.

Out of the total number of 162 visitors, there were 10 participants in the digitization workshop and 6 community items were digitized. Figure 5.44. shows a community-contributed digitized artifact. The archive gathered the digitized ephemera that included letters, greeting cards, postage, business cards, telephone records, photographs and manuscripts. These were then linked to the artist's network of artist friends and acquaintances (personas).

5.6.3 COMMUNITY THEME DAY 2: DIGITIZATION FOR THE COMMONS

What is the value in cultural openness and the Culture Commons? How do Internet, technology and social networks affect the development of the Culture Commons? How could museums and audience get involved in the Commons movement and contribute to Open Knowledge? These questions served as the backdrop to the digitization workshops and the digital archive on the second installation. The intention was for the audience to have unrestricted access to their heritage, so that trust and willingness to participate in the museum's activities could be encouraged. Thus, together, a body of open digital

Fig. 5.40. Community-contributed artifacts for digitization.

heritage could be compiled that serves both the museum and its user communities. Such openness could generate exposure to the museum collections, allow the community to become a stakeholder and promote for greater interaction with the audience.

Fig. 5.41. *Top*, Panel debate on digitization and Culture Commons; *bottom*, Digitization on Day 2.

On the second theme day, our design intervention continued gathering additional archival material from the museum's community. We also co-curated digital artifacts from the public domain online, assisted the community to document their historical artifacts. Simultaneously, lectures and panel discussions were organized on the theme of Art, Archives and Commons. Here, the community was exposed to the cultural discourses of Open Knowledge, Public Domain and the Cultural Commons aligned to our digitization workshops.

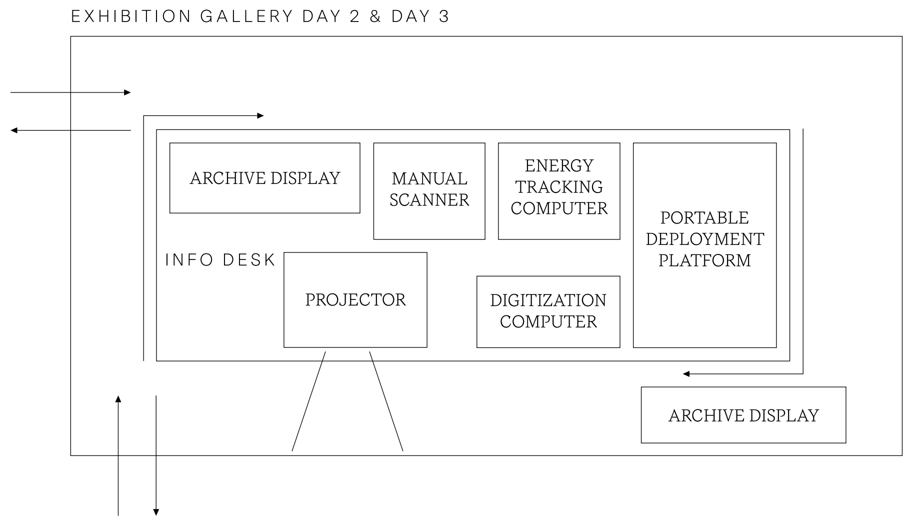


Fig. 5.42. Layout of the Digitization Workshop in the Large Exhibition Gallery on Day 2 & 3.

The digitization workshops were held in the larger exhibition gallery of the museum. Our design intervention continued with a digitization set-up similar to the first installation. Artifact-donors were again assisted in the digitization process to scan their heritage. Additionally, a curator workstation was installed alongside the digitization workshop to allow the museum curators to undertake digital curation among the museum audience. An image projector was located by the workstation that linked to the curator's computer to allow the audience to view the step-by-step actions of adding artifacts to the online archive. In some instances, members of the museum audience were able to clarify and add to certain archival materials or even present their own memories of the subject matter.

The curators also combed through Public Domain and Cultural Commons sites such as Wikipedia to find related micro-historical material that could be linked to the archive. Our digital archive allowed the curators to upload and tag scanned archival material in small increments. During the day, personal narratives related to Gallen-Kallela and local memories of the Tarvaspää area were also gathered from the community. Out of the total number of 69 visitors, there were 8 participants in the digitization workshop and 5 visitor items were digitized.

5.6.4 COMMUNITY THEME DAY 3: REMIXING AND DIGITIZATION

Remixing museum collections is a relatively emerging concept. “Novel assemblages consisting of already-existing material – whether material that is found, or that is intentionally preserved in archival institutions – can be seen as fresh, interesting and even political.”[89] At the Gallery One of the Cleveland Museum of Art “remixing” has been implemented via interactive installations.[90] Here one can add layers of personal information, negotiate with the heritage collections through a digital interface. We organized “remixing” at the Gallen-Kallela Museum with children and young adult audience of the museum’s community both inside and outside the museum. The theme of the event was about “remixing” cultural heritage. The goal was to utilize existing collections and open them up for re-interpretation by the museum’s user community. This resulted in new derivative works of art that were then digitized and uploaded to the digital archive.

The museum organized a remixing stand, where we assembled reprinted old photographs of Gallen-Kallela and his friends from its collections. Paints and brushes were made available. Children were invited to join in painting over the old photographs and add their own interpretation of historic events. In the digitization workshops, children were invited to display their skills of sketching and drawing. They were asked to choose one of the Personas from the digital archive and draw or sketch their own interpretation. The children were then provided with our designed A5 sized printed card sheets that served as their canvas. This card was designed to be handled by the autonomous scanning robot. The back of the card contained copyrights information.

Fig. 5.43. Digitization and Remixing on Day 3.

The young audience was guided in the digitization process to allow them to utilize our scanning system to digitize their sketches. At first, they were able to access the robot user interface, start a new scanning workflow, name and tag their artifact, check previews and publish the scans to a local server. These scans were then uploaded into the archive alongside the same Persona that they had chosen to interpret. 7 new remixed versions of Personas were added on this day.

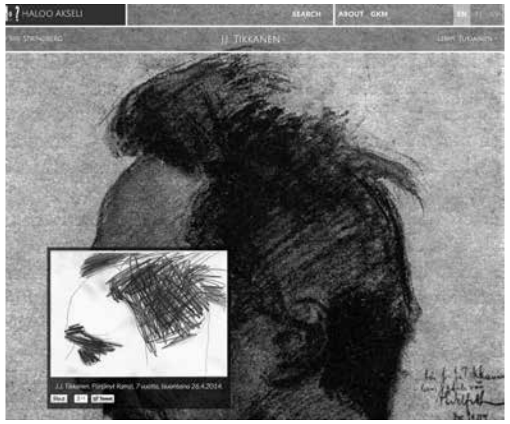


Fig. 5.44. *Top*, a visitor's drawing of an original sketch by Akseli Gallen-Kallela of J. J. Tikkanen from the museum's collections; *bottom*, a sketch interpretation of Ida Aalberg.

ARTIFACTS COLLECTION 5.6.5

We were able to community-source 18 artifacts of heritage value over 3 days of community events at the museum. These consisted of historical photographs, letters and other ephemera. Our scanning system functioned for 3-5 hours in context of the community days and also digitized a portion of the ephemeral collections of the museum.

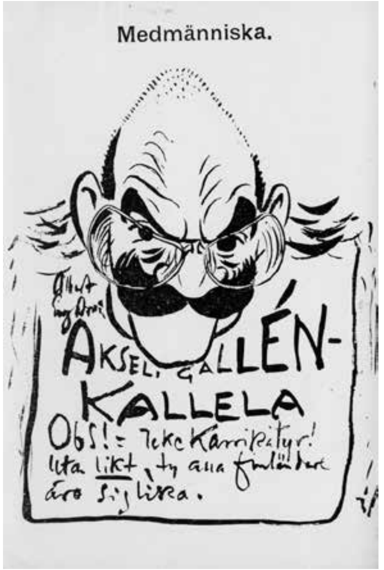
Our process activated the digital archive during the community days. 64 profile pages were created and 88 images uploaded. New heritage content from the community was added to the archive with the necessary metadata as per archival standards. As a result new collections heritage was available on the Web for the community. We also documented personal stories and narratives related to the paintings of Gallen-Kallela from 18 participants. The curators were able to digitize, upload and tag crowdsourced archival material into the archive in small increments. In few cases, participants were able to clarify and add to certain archival materials or even present their memories of the subject matter. Thus, our design intervention in many ways built new engagement and benefitted both the museum and its audience.

ENERGY MONITORING OF THE DIGITIZATION PROCESS 5.6.6

On the community Theme Days, energy consumption of the digitization process was publicly monitored and recorded. On the theme days, energy meters were used to measure energy consumption. The energy calculations are described in 5.7. Meters were installed for the purposes of:

1. To record the energy consumption of the scanning system and its user interface computer.
2. To record the energy consumption of the display systems including the image projectors and archive browsing computer. Figure 5.35 illustrates the final setup used.

The museum audience were able to witness the energy consumed in the digitization processes conducted all day long on the Theme Days at the museum. This allowed them to understand the energy



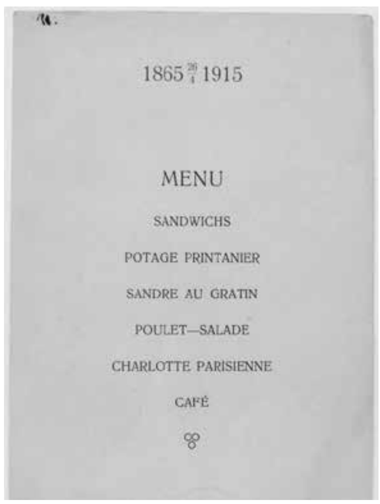


Fig. 5.45. Digitized ephemera in the digital archive.

costs of digitization for museums and archives and the costs of preserving community submitted heritage. The energy meters served as a mediation between energy use to preserve memories and the audience own perception of the digitization process.

FEEDBACK ANALYSIS & SYSTEM DEFICIENCIES 5.6.7

We created a feedback form for the audience with questions about their experience of our design intervention at the museum. They had to rate their experience on a scale from 1 to 10:

1. Was participation beneficial to you? (PARTICIPATION)
2. How was your experience of the digitization workshops? (DIGITIZATION WORKSHOPS)
3. Was the scanning system suitable to the museum? (SYSTEM SUITABILITY)
4. How was your experience of the digital archive? (DIGITAL ARCHIVE)

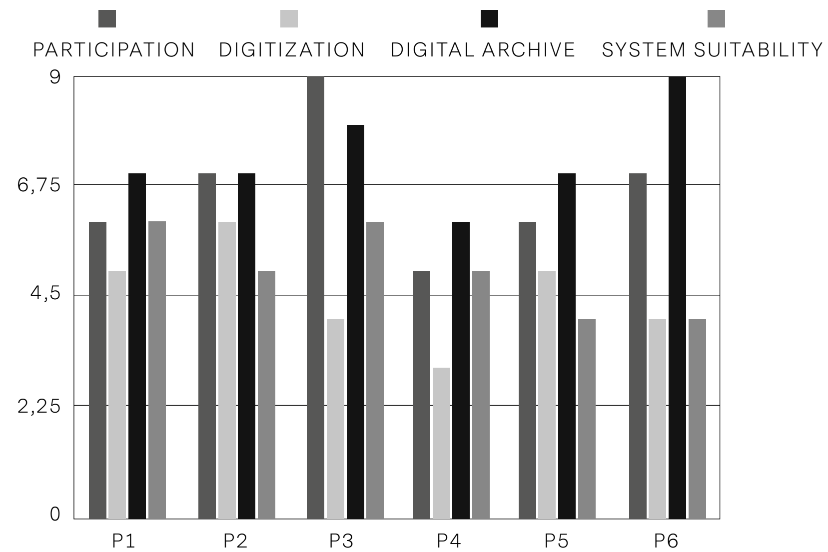


Fig. 5.46. Feedback Analysis. Members of the audience were asked to rate their experience on the first day.

Although, our design intervention was successful in fostering community heritage and engage the museum audience in the digitization process, there exists several technical, systemic and strategic challenges. Our scanning robot and the portable deployment platform were not operationally successful and they need further technical development and usability tests. The digital archive needs increased functionality to allow online participation and usability re-examined. The audience of the museum is in the preliminary phase of understanding copyright laws in the donation and digitization of historical artifacts. Therefore, a long-term strategy is needed for the digitization of the collections of the Gallen-Kallela Museum. The visitor/participant feedback and the recorded outcomes of our digitization project point to several failures:

Failure 1: Our digitization system failed on multiple occasions. We could not reliably conduct the digitization process during the community theme days. On the first day, after performing a single scanning run, the robot failed to initialize. Despite corresponding sanity checks and running the troubleshooting program to individually test each of the robot's main functions, the robot did not respond. We had to dismantle the entire outer casing to check the cable links attached to the robot arm.

Failure 2: Feedback received from the audience about the archive was varied. To some it was interesting to experience a digitally interpreted social network from the 1920s and difficult to others who are not too familiar with the concept of an online archive. Thus, the generational use of a digital archive needs to be further explored. The literal reinterpretation of a phonebook into an online archive may not necessarily result in a coherent user interface design. At the moment, a major deficiency of eliciting participation in digital curation from the audience is the absence of an online "Submit" button on the user interface. This could have provided a useful participatory feature to the archive. Using a submission form, the museum's online audience could have added, edited and tagged their own historical material and memories to the archive.

Failure 3: The concepts of cultural commons, creative commons licenses and public domain are relatively unknown among GKM's audience. Awareness about open content, linked data and Cultural Commons needs to be expanded further.

Failure 4: Despite the approaches offered by the design intervention, no long term strategy for implementing digitization strategies nor a systematic framework of combining community events with digital happenings was developed during 2013-14. The re-activation of the museum collections remained incomplete. Work on building the social network of Akseli Gallen-Kallela and the associated artworks and heritage were not continued after the intervention due to lack of resources.

UNRESOLVED TECHNICAL ISSUES 5.6.8

The robot arm has a small suction cup with an outer diameter of about 25 mm. Items whose materials are soft, flexible, supple, pliable, bending tend to be sucked into the suction cup, and the material outside of the suction cup may crinkle or bend due to even low suction. This uneven pressure is then noticeable in scanned images. Extremely thin paper materials might easily be damaged, even when low levels of suction are used. The input stack should ideally contain items whose size and material characteristics are very similar. This is because setting the robot's vacuum suction level needs to be tuned to the type of material.

The design intervention used an A4 (210 mm x 297 mm) sized document scanner. The digital scanning assistant had a certain degree of rotational variability when picking an item from the input tray and placing it onto the scanner. When the dimensions of the item start to become close to the width of an A4 size, this rotational variability could sometimes cause issues because the item needs to be more exactly aligned rectangularly with the scanner, otherwise parts of the item may not be visible to the flatbed scanner.

Although an A4-sized document scanner was used, in our case the design intervention was generally not able to scan A4 sized items. This is because there was some variability in rotation when picking items and placing them onto the scanner. The end piece of the robot arm does not rotate which could help to make such fine tuning adjustments.

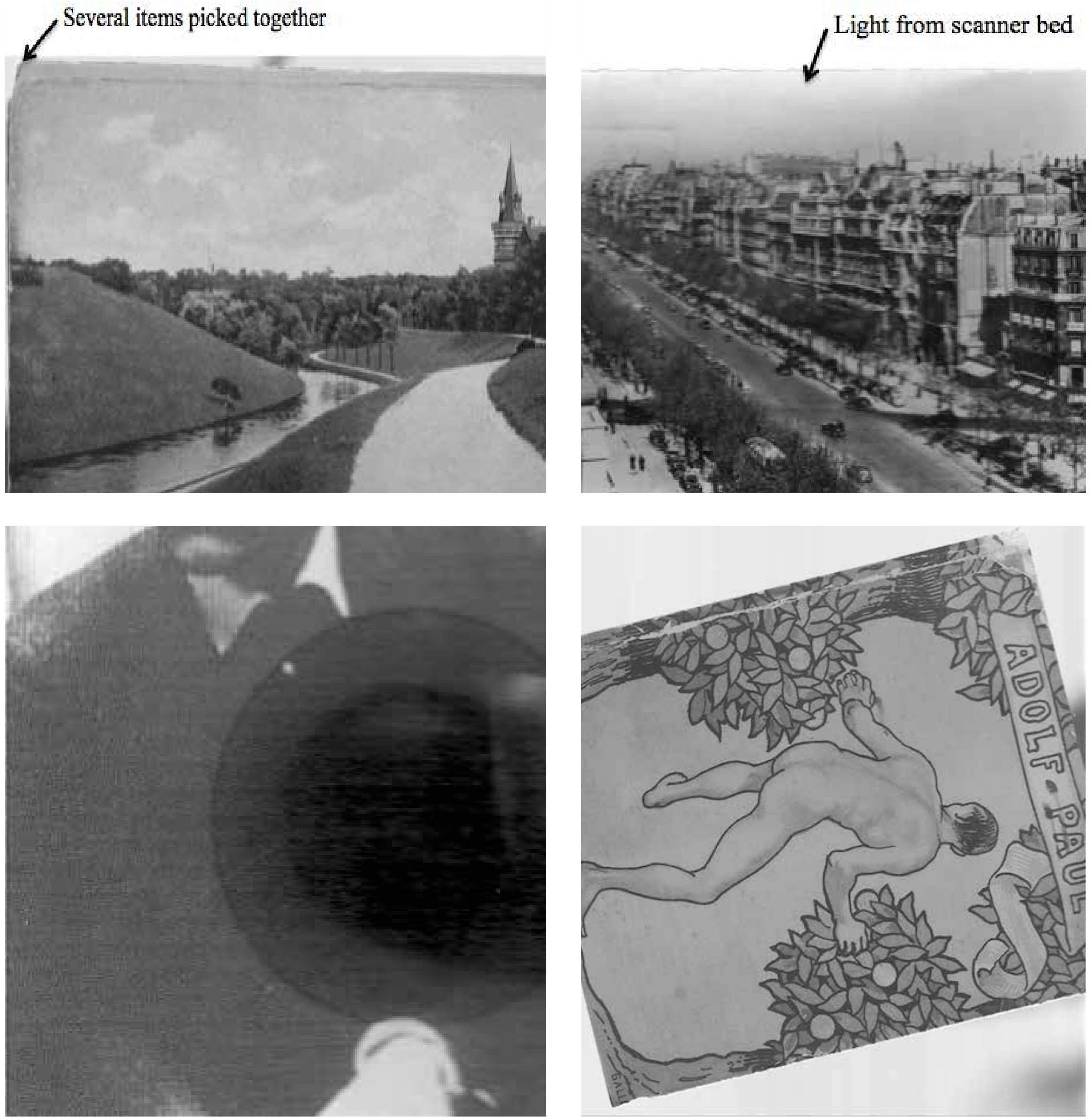


Fig. 5.47. Material Constraints experienced during digitization. Images by James Reilly. *Top left*, Thin, porous postcards in a stack may cause multiple items to be picked by the vacuum cup; *top right*, significant curl may cause variable focus, or light bleeding in from the top of scanner because the suction cup only puts pressure in the center of the item during scanning; *bottom left*, the vacuum cup is visible in the scanned image of a very thin photo with low opacity because the light from the scanner shines from underneath the item; *bottom right*, item size and rotational variability may affect maximum item size used.

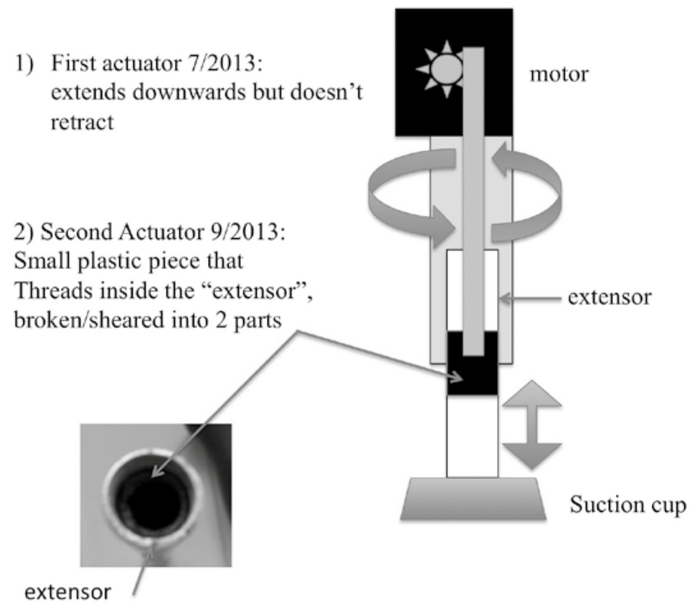


Fig. 5.48. Hardware issues: the stiffness of the suction cup holder joint repeatedly damaged the linear actuator of the robot arm. Illustration by James Reilly.

Project Gado has begun work on a redesigned robot arm's end-piece and vacuum cup attachment, to address some of the limitations.[91] This would apply even amounts of pressure across the entire surface of an item during picking and placement onto the scanner. That would help to provide a thick and consistent background behind the entire item during scanning, and to make sure the item is properly seated on the scanner bed.

The robot arm has both a rotational component (radius, angle) provided by a central stepper motor in the X,Y-plane and a translational component in the Z-axis by using a linear actuator to raise and lower the vacuum cup. If the robot instead used a linear motor in the X,Y-plane, that might possibly remove some rotational variability in picking and placing items. This would necessitate a very different mechanical design approach and would be an area for further study.

5.6.9 COMPARATIVE ANALYSIS

We initiated this project at GKM with a certain criteria needed for the digitization infrastructure for ephemeral heritage. The infrastructure had to be low-cost, low energy-use, portable, aimed at ephemera and subject to participation by the user communities of the museum. Despite initial technical difficulties, our custom digitization infrastructure provided the above and proved to be beneficial than the various other systems we examined. Our system can autonomously digitize ephemera unlike the others that require constant handling of archival material, thus enhancing productivity. It can digitize ephemeral heritage at 150/300/600 dpi resolutions, which is sufficient for small-sized single-page documents. It has low energy consumption. The system can be easily assembled and deployed in remote museums and archives and other heritage locations. It is inexpensive to build, most parts are open source, 3d printed and made up of off-the-shelf components. The software is open source and designed to be utilized by non-technical museum audience. Our system builds on the strengths of a local participating community, and also online hardware and software communities by actually involving them in the nitty-gritty details of heritage digitization. This approach is unique and innovative as it provides an alternative open-source, low-cost, participatory digitization as compared to proprietary, black-boxed, commercial and expensive digitization infrastructure. In the following table we briefly present the advantages of our system over traditional digitization infrastructure:

Table 5.7. A comparison of existing digitization infrastructure versus the system designed and deployed at GKM.

Digitization Infrastructure	Ephemera / Quality / Productivity	Energy	Portability	Partcipative	Cost	Proprietary vs open source
Large-Format Scanning Infrastructure	Can digitize ephemera, high scan quality, low productivity.	High energy consumption.	Not Portable. Cannot be deployed in remote locations.	Not participative. Can be operated by only technical personnel.	Expensive, requires customization, and special order from manufacturer. Also needs servicing contract.	Not open source. Only serviced by the manufacturer or licensed agent.
Medium-Format Camera-based Infrastructure	Can digitize ephemera, high scan quality, low productivity.	Medium to high energy consumption (due to additional lighting setup)	Not Portable. Cannot be deployed in remote locations.	Not participative. Can be operated by only technical personnel.	Expensive. Requires additional investments in lighting equipment. Also needs servicing contract.	Not open source. Only serviced by the manufacturer or licensed agent.
Digitization Infrastructure at GKM	Can only digitize ephemera, 150/300/600 dpi resolutions, autonomous scanning leads to high productivity.	Low energy consumption.	Portable. Can easily be assembled and deployed in remote locations.	Participative. At GKM, the communities participated in digitization.	Affordable. Parts can be easily 3d printed and CNC-milled; electronic components are easily available off-the-shelf; can be assembled for under 700 euros. Can be serviced or repaired easily.	A majority of the hardware components are open source including the software.

5.7 INFRASTRUCTURAL ENERGY ANALYSIS

5.7.1 OVERVIEW

We inventoried the various components of the media infrastructure of the scanning system. This included all hardware, interfaces, devices and associated peripherals. We also conducted various experiments with energy measurement of the digitization process. From this we calculated the emergy and energy consumption of the system. See 2.5 for general methods. The goal of this exercise was to quantify the energy and emergy footprint of a critically-made media artifact placed inside a museum.

5.7.2 CENSUS

We conducted a census of the various components of the scanning system as shown in Table 5.8. This includes the hard media infrastructure i.e. flatbed scanner, digitization laptop, robot arm and associated parts.

5.7.3 EMERGY OF MEDIA INFRASTRUCTURE

The scanning system is made up of low embodied energy components, as shown in Table 5.9. As introduced in 2.3, the calculation of emergy entails taking into account, the energy used to manufacture and construct the various components of the media devices. The per-unit emergy has been compiled from several studies.[92]

5.7.4 ENERGY CONSUMPTION OF MEDIA INFRASTRUCTURE

The energy measurements depicted here are originally from the Project Notes.[94] We conducted experiments in two setups as a normal run of the robot arm process using our own application. First, we monitored the energy of the USB hubs power source and the robot, and secondly, we monitored the entire setup (power sources, robot and computer). The results for the two iterations of the robot are in Figure 5.49 and Figure 5.50.[95]

Table 5.8. Census of media infrastructure of the scanning system

COMPONENTS	QUANTITY	DETAILS
Flatbed scanner (include power adaptor)	1	CanoScan Lide 210
Base Motor	1	HS-785HB 3.5 Rotations, Max. Torque 183 oz-in.
Vaccum Pump (include power adaptor)	1	12 v - 12 w operation, 1/4" barbs, 0-16" Hg vacuum range, 0-32 psi.
Tubing & Adjust Valve	1 + 1	Standard PVC tube, PVC valve.
Suction Cup Assembly	1	3D printed, ABS Plastics
Linear Actuator	1	L12-I Micro Linear Actuator with Internal Controller by Firgelli.
Metal cup barb	1	
Microcontroller	1	Arduino UNO
Gado 2 Circuit Board	1	
USB Cable	1	
IPEVO camera	1	HD camera
Electrical Adaptor	1	1 Ampere
Robot arm casing	1 + 1	3D printed, ABS Plastics
Rear arm piece + Front arm piece	1 + 1	3D printed, ABS Plastics
Bottom Plate	1	3D printed, ABS Plastics
Plastic Legs	4	3D printed, ABS Plastics
USB powered hub	1	
Cables & wires	2 meters	22 AWG (american wire gauge) for electronics, insulated electrical wires for power supply.
Laptop (include power adaptor)	1	MacBook pro and power adaptor.
Steel hardware	1 kilogram	screws, nuts, hinges, roof, legs etc.
Plywood (waterproof)	3 kilogram	Various sized pieces.
Foam filling	0.5 kilogram	
Energy Meter System	1	PlugWise

Table 5.9. Energy of Media Infrastructure[93]

COMPONENTS	QUANTITY	PER-UNIT EMERGY GIGAJOULES (GJ) - per kilogram	TOTAL EMERGY GIGAJOULES (GJ)	REPLACEMENT TIMESPAN (years)
Flatbed scanner (include power adaptor)	1	0,5	0,5	4
Base Motor	1	0,1	0,1	2
Vaccum Pump (include power adaptor)	1	0,2	0,2	2
Tubing & Adjust Valve	1 + 1	0,05	0,1	>5
Suction Cup Assembly	1	0,075	0,075	1
Linear Actuator	1	0,25	0,25	1
Metal cup barb	1	0,01	0,01	>5
Microcontroller	1	0,25	0,25	2
Gado 2 Circuit Board	1	0,25	0,25	2
USB Cable	1	0,01	0,01	2
IPEVO camera	1	0,25	0,25	2
Electrical Adaptor	1	0,1	0,1	2
Robot arm casing	1 + 1	0,095	0,19	>3
Rear arm piece + Front arm piece	1 + 1	0,095	0,19	>3
Bottom Plate	1	0,095	0,095	>3
Plastic Legs	4	0,095	0,38	>3
USB powered hub	1	0,05	0,05	2
Cables & wires	2 meters	0,01	0,01	2
Laptop (include power adaptor)	1	4,5	4,5	4
Steel hardware	1 kilogram	0,02	0,02	>20
Plywood (waterproof)	3 kilogram	0,015	0,045	>10
Foam filling	0.5 kilogram	0,085	0,0425	>10
Energy Meter System	1	0,095	0,095	4
			7,7125	

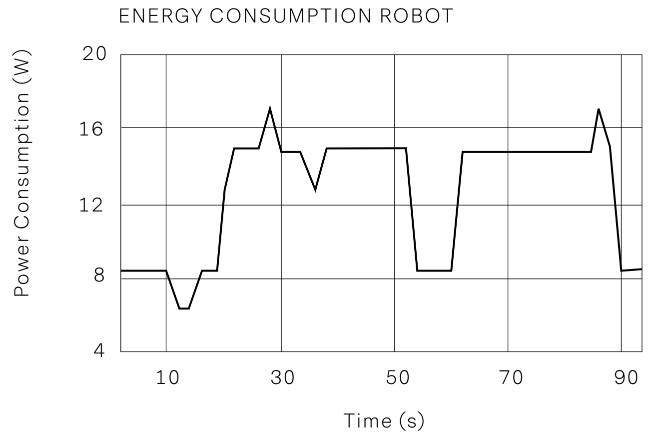


Fig. 5.49. Energy consumption of the robot. Illustration by Agusti Pellicer.[96]

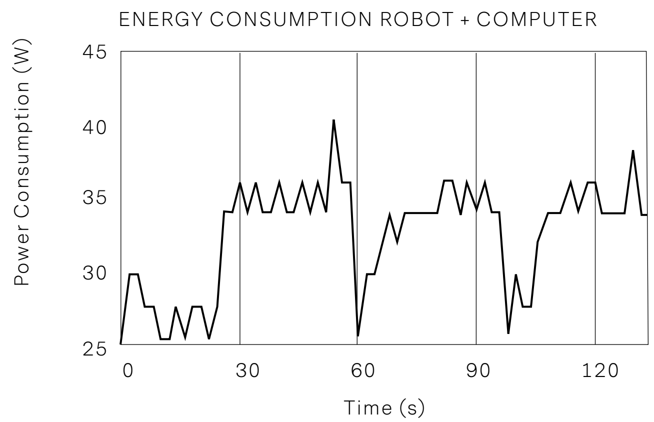


Fig. 5.50. Energy consumption of the whole setup. Illustration by Agusti Pellicer.[97]

As shown in figures 5.49. & 5.50., the spikes correspond to the vacuum being on. In figure 5.49, the first 15 seconds the power consumption remains the same due to the application being started, the user introducing the folder and the tags, and waiting for the robot to be ready. The graph shows that the connection to the robot and setting up all the devices don't have an impact on the energy footprint of the overall system. Once the robot has initiated and is running, the power consumption rises until the robot drops the item onto the output tray. A scanning operation takes around 40 seconds, 35 seconds of which are with the vacuum being on.

In figure 5.49. we have a scanning run with two items and in the figure 5.50. we have a run with 3 items.

Table 5.10. Energy consumption of robot arm

STATUS	POWER CONSUMPTION (w)
Idle	6.29 - 8.42
Vacuum (Maximum Value)	16.94
Vacuum (Half Power)	12.68
Arm	Same as idle or 10.55
Actuator	Same as idle

In Table 5.10. we can see a detailed breakdown of the power consumption of the various parts of the robot. The other parts of the system (webcam and scanner) don't have an impact on the energy footprint, but testing alternative settings on the scanner yield interesting results. When the scanned image is saved to the file format TIFF the energy is as we see from our experiments, but if we switch to the PNG format, the energy of the whole system (robot + computer) climbs to 38.22W. Also, saving to PNG delays the process by 2 seconds. Due to this testing, we decided to save our scans using the TIFF format and during the automatic cropping process, we converted them to the PNG format.

During the digitization workshops at GKM, the energy consumption of the laptop was 35 Watts (W). The robot arm and its powered USB hub consumed 10 W when actively digitizing printed items and

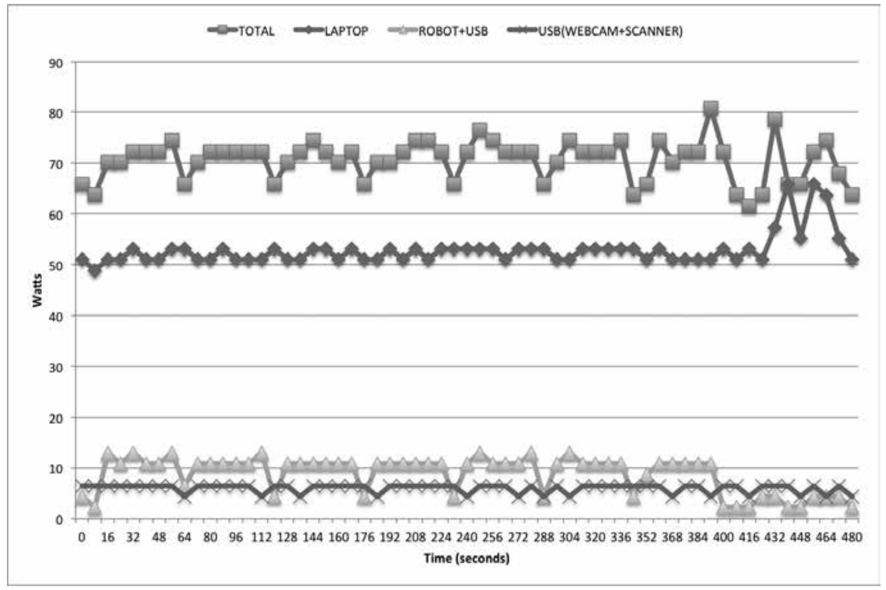


Fig. 5.51. Energy measurements of the scanning system. Illustration by Agusti Pellicer.[98]

5 W when the robot was idle. The document scanner, webcam and powered USB hub together consumed 8 W. The digitization computer typically used 50 W and was as high as 60 W at times. The total was 70 W during active scanning. We have assumed that there is negligible power loss at the Plugwise measurement units and at the power strips whose length was kept at a minimum. If the scanning system is run constantly for one hour of digitization, its average energy consumption shown in Figure 6 was about 0.07 kWh. The price for that hour of digitization is then: 0.115 EUR/kWh × 0.07 kWh = 0.00805 EUR excluding value added tax (VAT). It took about 50 seconds to scan one item using the setup shown, or about 70 items per hour. The resulting energy price for the semi- automated digitization of one item was then approximately around: 0.00805 EUR/hour ÷ 70 items / hour = 0.000115 EUR/item excluding VAT.[99]

5.7.5 RESULTS

Our semi-automated scanning system at the Gallen-Kallela Museum used 0,07 kWh of electrical energy (much lower than a manual flatbed scanner or a drum scanner, none of which are open source nor autonomous). From our census and emergy calculations, we found that the system has an embodied value of 7,7125 GJ (compare this to design intervention 1: Light is History that had an emergy of 6,31 GJ, or the Cooper Hewitt's 1595,5 GJ).

5.8 SUMMARY

Our design intervention at the Gallen-Kallela Museum exposed the invisible operations and supporting infrastructures of digitization to its audience. It initiated excavation into the context of digitization for small museums with limited funds and personnel. The project-led approach aided us to bring forward concepts and practices from the previous design intervention Light is History. Our methodologies opened up the hidden black box technologies and processes of scanning and digitization.

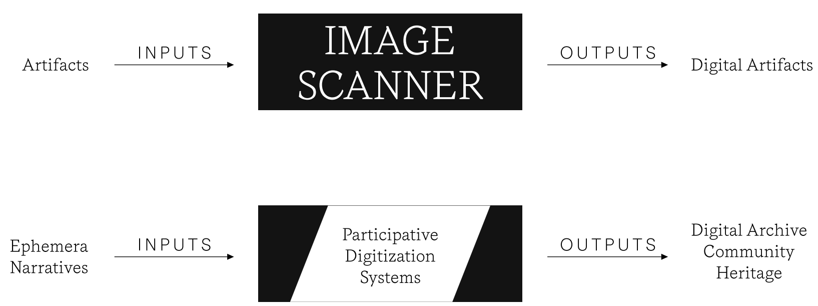


Fig. 5.52. The transformation of the image scanner into an ecological media.

Just like ephemera itself, the infrastructure to digitize ephemera in this design intervention was designed to be small-sized, micro-scaled and micro-structured. In a way the scale and proportions of the system design was adapted to the physical form and nature of ephemera, to extend its physicality to a digital existence. The infrastructure also had to be comprehensive, starting from the UI of the scanning system to the collections back-end of the CMS. Open-sourced inexpensive hardware, free software, and the small scale of the digital fabrication machines were crucial to the infrastructuring process. The low energy-use of the digitization system caused a smaller energy footprint offering a sustainable and low-cost approach to small museums with limited budgets. The participation of community allowed the infrastructure to be publicly examined and accessed.

The digitization infrastructure in GKM was micro-scaled and micro-staged to deal with micro-histories of AGK. This happened in several areas, such as in the structure of the digital archive, the structure of the deployment platform and the scale of the digitization artifacts. The archive was structured to be a micro-blog and was inspired by micro-blogging platforms. Dealing with micro-packets of heritage allowed increased participation from the museum community. The deployment platform was designed to be portable and easily transportable and applies to small and remote museums without digitization infrastructures and dedicated personnel. As such the dimensions of the platform are also scaled to an appropriate size for a single user. This user could easily and quickly setup the platform and initiate scanning runs within a small space. The designated ephemera size is similarly of A5 media size and the platform is only suited for small ephemera. This micro-structuring of digitization allows museums to digitize and add micro packets of heritage (A5 sized digitized ephemera) steadily to expand archive content.

Our intention was to build a low-cost digitization infrastructure for small museums with limited funds and resources. As such, infrastructure in this study has been mostly conceived through open-source hardware and software. Our automated digitization system is low-cost and can be assembled in a low budget which includes the cost of procuring the hardware components, the flatbed scanner, webcam and plywood for CNC milling. For the software, we used the open-source Project Gado as a base reference for the code that we expanded using open-source libraries. As a result we created a new GNU/Linux application and tools so that users could interact with the digitization system. We released the original design of portable deployment platform under a Creative Commons license. During this process we were able to contribute back to Project Gado too. The hardware design files are licensed Creative Commons BY-SA 3.0, that allows copying and redistribution of the material in any medium or format, and can be remixed, transformed, and built upon for any purpose, even commercially. The code on GitHub is a contribution back to the open-source community.[100]

A key methodology used in our design intervention was Critical (hands-on 'making' supplemented and extended with critical reflection on technology) Remediation (representation of an older medium within a newer),[101] or similar to what Hertz describes as a method of reuse that is focused on challenging institutional structures through the tactical repurposing of media technologies.102 Our intentions were always at a pilot-level short-term demonstration of the possibilities of community participated digitization within a heritage institution and thereby challenging the conventional methods of digitization and long-term preservation. We also employed various other methods such as community-sourcing and microstructuring, those that were brought forward from our previous design intervention Light is History. The technologies we used were open source, and are under collaborative development. From our design intervention it appears that open source infrastructure is a low cost, low-energy bridge for small heritage institutions. As a collaborative team of researchers, programmers and curators, we were engaged in multiple aspects of the design intervention including research, design, programming, making, cultural production and communications. From these we gained considerable knowledge in the fields of copyrights licensing, archiving, electronics, 3D fabrication, software design, scanner equipments, energy infrastructures, publishing and the Commons.

Although, much prototyping and experimentation needs to be yet conducted to make it into a long-lasting infrastructure, the design intervention shows that digitization can be low-cost and performed without substantial human resources and material-dependence. The intervention extended critical reflection about the invisible digitization infrastructures and materialities of the museum. It also extracted critical thinking about the energy use of such infrastructures and displayed the embodied energy thereby contained within. Our analyses show that visibility of the digitization infrastructure encourages awareness and public participation. Our design intervention presents an alternative model to small museums in fostering their communities in the digitization and long-term conservation of heritage. It shows that digitization can be low-cost and performed without substantial human resources and material-dependence. It demonstrates that open source software and hardware could be utilized in place of proprietary equipment. Community participants can be involved with the digitization process and participation in the digitization process could increase engagement with the museum's collections. Thus, together, a body of open digital heritage could be compiled that serves both the museum and its user communities. Such openness could generate a wider global exposure to museum collections and allow communities to become significant stakeholders.

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6

DESIGN FRAMEWORK

6.1 INTRODUCTION

"In a digital culture of apparent, virtual, immaterial realities, a reminder of the insistence and resistance of material worlds is indispensable.." [1]

The findings of this dissertation present a contemporary museum that is steeped in mediation and materiality. Beyond traditional modes of representation, screens, archives, algorithms and computing processes play a significant role today in museums and institutions of cultural heritage. An enormous amount of media infrastructure is required to create, support and distribute these digital mediations, representations and processes. This infrastructure is composed of a complex and historical body of media devices, most of which are an assortment of black-boxed proprietary hardware and software technologies. Energy consumption is relatively high and embodied energy of media infrastructure remains undocumented. The expanding materialities are the high energy use of media devices and data centers,[2] mining of rare earth minerals and a growing environmental impact. Behind every act of heritage digitization and digital representation lies a chain of material resources, silicon chip manufacturing,[3] and dystopian toxic lakes.[4] The life-span of this media infrastructure is limited and not only obsolescence drives a perpetual upgrading resulting in colossal digital rubbish, but also, "used and obsolete media technologies return to the earth as residue of digital culture, contributing to growing layers of toxic waste…."[5]

The dissertation presented here began as an attempt to understand the environmental impact of the museum, to examine the materialities of its media infrastructure. The research started out with these questions (see 2.4): What domains of media infrastructures of the museum are energy consuming? What practices could help develop alternative media infrastructure that is ecological? and What design guidelines (framework) could assist museums to build media infrastructures with low environmental impact?

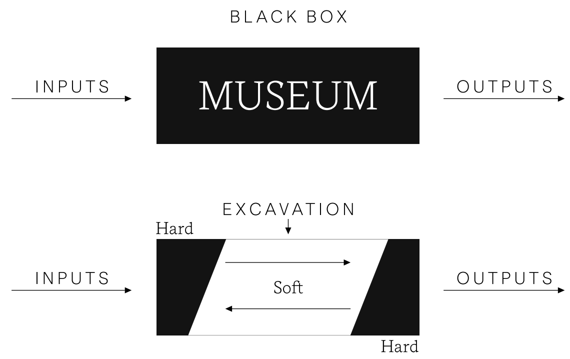

Fig. 6.1. *Top*, The museum blackbox; *bottom*, the excavation of the black box. Illustration inspired from: Garnet Hertz and Jussi Parikka, "Zombie Media: Circuit Bending Media Archaeology Into An Art Method," *Leonardo* 45, no. 5 (2012): 426-427.

The primary motivation was to dismantle the black box of the museum, to reveal its media infrastructure, its embodied materialities. By doing so, the museum's internal complexity could be laid bare, to uncover from its body the mediating roles of its various constituents. This would then present ways to develop constructive and critical methods for media infrastructures to serve museums weighed against embodied energy and energy use.

The study approached the research problem and questions through — "the 'cold gaze' of Media Archaeology."[6] As such it was interested in "the physicality of technical media, including computation through which cultural memory is articulated."[7] The study also adopted an 'infrastructural disposition' to examine the museum to foreground physical systems and processes of its media infrastructure, thereby bringing into relief its unique materialities.[8] Thus, if the museum (as an apparatus, as an archive) is a collection of artifacts and media infrastructure in various forms, then the methodology was an archaeology of the infrastructure (as an archive), to uncover its materiality. This was more than the "mere cataloguing of the apparatus [museum], rather it was concerned with the investigation of the scenes in which the apparatus [museum] found its way into the spheres of research and experience."[9] According to Ernst, this methodology is "an un-biased archaeology of the apparatus [museum], as a study of how stories and memories are recorded, in what kind of physical media, and in what kind of processes and durations."[10]

Following this methodology, the answers to the research questions, as discovered through Excavation (Chapter 3) and Design Interventions (Chapters 4 and 5), form a research space (6.2) around which methodologies could now be constructed. This chapter unites the findings, concepts and synthesizes a framework for the design of media infrastructures for museums and digital heritage. The main contributions are outlined and the challenges involved in the study are summarized. Future work would entail the evaluation of the design framework in its entirety or in parts at a museum or a heritage institution. Further studies are proposed in the charting the media infrastructures for digital heritage, including obsolescence, digital memory and their environmental impacts.

6.2 RESEARCH FINDINGS

Earlier, we examined a 'deep time' history of the museum in 2.2, and followed it up by a historical study of the Cooper Hewitt in 3.3. From this we discovered the origins of the formation of the museum, how representation became dominant over knowledge and community. How the media infrastructure of the museum gradually evolved to support collection, display and interpretation of artifacts rather than the exchange of knowledge and spaces for communication. The entanglement of energy and museum infrastructure was explored in 2.3. This contextualization continued in the historical examination of the electricity meter in 4.2 and the image scanner in 5.2. We found that infrastructures needed for a museum for its daily immaterial practices have expanded in materiality in the form of media and computing hardware, content distribution and storage systems. These media infrastructures in turn are linked to energy footprints and natural resources. Then we excavated the museum, studied its hard and soft media infrastructures (3.4, 3.5), and conducted an infrastructural energy analysis (3.7). We examined two sets of materialities embedded in the infrastructure, one that was expressed in the architecture, the tangible devices (hard) and the other that existed in the computational systems (soft), that dealt with the museum's digital content. Through these, we found substantial energy use of the media infrastructure and high emergy of its components. Finally, we designed and deployed two design interventions as elaborated in chapters 4 and 5, as research objects and alternatives. These resulted in operative methodologies that may assist toward an ecological design of museum infrastructure.

In this section we enumerate the various findings from applying a customized archeological methodology to museum infrastructure as described in section 2.5. We compile insights gained from the excavation of the museum and the design interventions. First, we examine the data from the infrastructural energy analysis of the Cooper Hewitt Smithsonian Design Museum. Next, we uncover the various methodologies and practices of the Museum. The same process is then applied to the design interventions. We conduct comparative energy and emergy analyses. Finally, we summarize the salient points of the findings of this dissertation.

EXCAVATION: ENERGY AND VISIBILITY ANALYSIS 6.2.1

From the excavation of the Cooper Hewitt Design Museum in chapter 3, we found that most domains of the media infrastructure were invisible and are high energy consuming as shown in Table 6.1. These have high embodied energy, are closed proprietary systems and loaded with imminent obsolescence. These black-boxed infrastructure have high embodied energy that is a significant factor when it comes to life-cycle decision making, migrating to an open system, repair and daily maintenance. See 3.7 Infrastructural Energy Analysis for more details.

Table 6.1. Museum: media infrastructure, visibility and energy use

MEDIA DOMAINS INVESTIGATED	VISIBILITY (public or internal)	STATUS
Media Exhibits +equipment	Visible Interface / hidden processes	High energy consuming, subject to obsolescence
Computing Hardware	Visible Interface / hidden processes	Energy consuming, subject to obsolescence
Mechanical Systems	Invisible	High energy consuming, main-tanenece and monitoring.
Architectural Systems	Visible	High energy consuming, main-tanenece and monitoring.
Convservation & Storage	Invisible	Moderate energy consuming
Data Center	Invisible	High energy consuming
Cloud Collections	Invisible	No Information avalable

As examined in 3.4., with the renovation of the exhibition spaces, the museum has now multitouch tables, screens and projections in virtually every room of the galleries that run continuously around the year. The energy use as such is much higher than previously. The media exhibit experience has increased the scale of the digital infrastructure and energy footprints to support such a museum-wide media exhibits system. The concealed mechanical systems are now boosted up from their previous configurations to simultaneously support the enlarged family of media exhibits and climatic control of the design artifacts. The historic architecture, the old medium, has been customized to include the new media, however, the fragmented spaces and large volume are not ideal for heritage artifacts.

The media infrastructure needed for the storage of artifact collections is another invisible component of the museum system. These storage spaces (examined in 3.4.3) are often equipped with extensive interior climate control to provide the desired stable interior climate for optimal conservation of objects leading to large economic and ecological costs. The energy footprints of digital collections are yet undocumented since they are located in high energy-intensive data centers and private cloud computing providers. Most of the invisible media infrastructure of the museum is subject to technological obsolescence. The fast-paced development of digital technology in hardware, software and storage capacities leads to a steady monetary and energy investment. As such, the museum would have to constantly improve infrastructures to maintain accessibility to the museum collections and to ward off in-built digital obsolescence.

Not encouraging in-house creative talent and instead utilizing third party vendors for the design and deployment of the media infrastructure is in the long-term not beneficial to the institution. This discourages the museum's own community from realizing its own media infrastructure, gain knowledge and develop related competence. It also prevents the museum from acquiring skills through recruiting appropriate technology experts. The museum has a thousand interfaces and forums serving the whole range of departments, daily processes and facilities operations. There is no unified space for the museum community as a whole. This has resulted in several black-boxes within the system where collections and expertise lie concealed.

However, the museum has most of its collections digitized and located in a central database. This is interfaced by an API that is open to the public for access, as discussed in 3.5.3. The API is effective in the long run since by its very central point of access to the entire collections database, it saves time and resources for the museum. Web or mobile prototypes can be easily built on top of the API, thus allowing quick testing of ideas. The digital collections are open under the United States Fair Use law and so are the metadata.[11] The 'openness' of the collections contributes to the increased visitation and online engagement.[12]

6.2.2 EXCAVATION: METHODOLOGIES

The study found several methodologies and practices at the Cooper Hewitt that point toward environmental responsibility (examined in 3.6). These include dashboarding energy use, designing open collections API, and a community within the museum that undertakes media research and publishes them openly online. Lets examine them in detail:

First, the methodology of dashboarding energy consumption that is built and developed internally at the Smithsonian[13]. The institution has been mapping the energy consumption of the infrastructure into a dynamic archive essentially consisting of energy analytics. This dashboarding is a real-time user interface, that displays current usage patterns of energy along with historical trends. This enables the museum to monitor its energy use.

Second, the Open Collections API was also conceptualized, designed and built in context at the museum.[14] Since the API is key to multiple internal operations used by in-house personnel such as the public (marketing) website, the collections and Tessitura, the ticketing system, hence it was constructed in context in the digital labs. Through the API, the museum has an efficient and open tool for negotiating multiple collections practices.

Third, the processes and results of the research and development conducted in the Lab of the museum are published in a blog.[15] Here, the in-house community contributes to the various articles and data. The museum encourages self-publishing, in a sense that everyone could submit their knowledge and expertise for digital publication. Some of the articles, processes and interviews are also published in the main marketing website. Thus, through documentation and publication, the museum attempts to open up its internal workings to the museum audience.

Finally, the Building Information Model of the museum provides a useful contextual interface for facilities management and operations, which also includes the tracking of the internal mechanical systems of the building.[16] This is an essential interface for monitoring of the various structural and mechanical components which are directly related to energy consumption.

Table 6.2. Areas and Actions toward Contextual Interfacing

AREAS	ACTIONS	METHODOLOGY
Media Devices	Inventorying	CONTEXTUAL INTERFACING
Energy consumption	Energy Analytics	
Digital Collections	Collections API	
In-House Developments	Self-Publishing	
Facilities Management	Building Information Model	

All the above actions could be grouped under Contextual Interfacing as shown in Table 6.2, when interfaces are built and customized in context at the museum to chart of media device & exhibits, energy consumption, collections, in-house R&D and facilities management.

6.2.3 DESIGN INTERVENTIONS: ENERGY AND VISIBILITY ANALYSIS

From our infrastructural energy analysis in 4.7. and 5.7, we found that both the design interventions have high visibility of their materiality, processes and functions to the audience as shown in Table 6.3. Both have low energy consuming media infrastructures and also have low emergy.

The hard media infrastructure of Light is History in 4.4., was sited in a public place, with its operations visible to the audience. Similarly, our scanning system was in operations at the Gallen-Kallela Museum with its workings openly accessible to the museum audience. Most of the hardware was repurposed or reused from existing and discarded technologies, as such their life cycles were extended.

Table 6.3. Design Interventions: media infrastructure, visibility and energy use

	LIGHT IS HISTORY	GALLEN-KALLELA MUSEUM	
MEDIA DOMAINS INVESTIGATED	Visibility (public or internal)	Visibility (public or internal)	Status
DEVICE	Visible Interface / open processes	Visible Interface / open processes	Low energy consuming
HARDWARE	Visible Interface / Microcontroller hidden	Visible	Low energy consuming
SOFTWARE	Visible to users / Open source	Visible to users / Open source.	Open Source community-developed
COLLECTIONS	Visible / Public Domain	Visible / Public Domain	community-contributed
ARCHIVE	Visible	Visible	community-participated

The APIs designed and built for the design interventions are available under share-alike creative commons licenses, and can be downloaded or forked without permission. The digital archives of the resulting collections are available online and open to participation by community.

6.2.4 DESIGN INTERVENTIONS: METHODOLOGIES

The design interventions clearly demonstrate in both cases critical methodologies that resulted in low-energy consuming media infrastructures, as supported by the infrastructural energy analysis. We also discovered several key operative 'actions' crucial to the projects. The design framework has been extrapolated from these methodologies, building upon the deficiencies we found in the excavation of the Cooper Hewitt. Overall, these three can be considered to be essential to the interventions: Microstructuring, Critical Making and Critical Remediation, incorporating within them the others such as Tactical Reuse, Circuit Bending, Counter-Remediation, Self-Publishing, Community-sourcing and Open Source.

Table 6.4. Design interventions: methodologies and visibility of infrastructure

MEDIA DOMAINS	VISIBILITY	METHODOLOGIES Light is History	METHODOLOGIES Gallen-Kallela Museum
HARDWARE	VISIBLE	Making	Making & Remediation
SOFTWARE	VISIBLE	Open Source	Open Source
COLLECTIONS	VISIBLE	Digital Archive	Digital Archive
INTERFACE	VISIBLE	Energy API	Collection Management API
VISUALIZATION	VISIBLE	Installation	Installation+Workshops
PARTICIPATION	VISIBLE	Community-Participated	Audience-Participated

A. Microstructuring Media

The media infrastructure of Light is History was micro-scaled to represent microhistories of energy artifacts. This micro-scaling of infrastructure took place in four media domains: Vitrines, Personal Narratives, Digital Archive and the Web API. Microstructuring assisted in the project management and the scale of engagement with participants. This helped us to efficiently organizing communications, design research, curating, digital asset management, programming, making (building) and logistics on a tight time schedule. Being a small team, we were able to mimic the museum's operations. We also found that Microstructuring was beneficial in terms of funding and resources, such that we could operate on a small scale, but without compromising the objectives of the research. The infrastructural energy analyses proves the low embodied energy and energy use of the project.

Table 6.5. Areas and Actions toward Microstructuring in the design interventions

AREAS	ACTIONS	METHODOLOGY
Media Devices & Interfaces	Scaled, collaborative, Open Source	MEDIA MICROSTRUCTURING
Daily Museological Tasks	Scaled, Prioritization, Shared	
Project Management	co-production, Shared, collaborative	
Community	Participation	

At the Gallen Kallela Museum, the media infrastructure of the remediation project was micro-scaled and micro-staged to deal with microhistories. This method was utilized in two main areas of structuring of the media archive and secondly in the structuring of the deployment platform and within that, the scale of the digitization artifacts. Microstructuring also assisted in the project management and delivery of the project on schedule. We have found that dealing with micro packets of heritage allows increased participation from the museum audience, and the structure also works well with linked open data, when micro packets of information from other archives are linked to it. The microstructuring of the deployment platform is especially beneficial to small and remote museums without digitization infrastructures and dedicated personnel. This allows curators to digitize and add micro packets of heritage (A5 sized digitized artifacts) on a daily basis to steadily expand the archive content. We discovered that Microstructuring was suitable to a small museum such as the Gallen-Kallela Museum which had small budget and limited personnel.

B. Critical Making

We employed the methodology of Critical Making to the design, construction and installation of Light is History. This allowed us not only to strike a balance between making and purpose, making and materiality but also to supplement and extend critical reflection on technology and society.[17] The methodology we think is a significant factor for environmental responsibility, going beyond mere design and construction of media artifacts, since the act of making made us reflect about the methods themselves. It made us consider the practicality, connectivity, interoperability and longevity of the media used and made the whole project 'time-critical', i.e., whether the project had short-term or long-term life-cycles and outcomes.

Table 6.6. Areas and Actions toward Critical Making of the design interventions

AREAS	ACTIONS	METHODOLOGY
Curating	co-curation	CRITICAL MAKING
Installation	co-production, co-design	
Energy Content	Self-Publishing, Archiving, Energy API	
Infrastructure	Reuse, Circuit Bending, Advanced Fabrication	
Software	Open Source	

For the project at at the Gallen-Kallela Museum, the method of Critical Making (in a critical 'maker' and 'DIY' spirit) was employed in the design, construction and deployment of the portable scanning platform assisted by electronics, robotics, 3D printing and CNC tools. We used open source and readily available off-the-shelf components. There was also a strong focus on reflective 'learning by doing' in a collaborative networked team. Through this, we gained detailed knowledge of components, their actions and various print media through making by reflection. Thus, Critical Making led us to an ecological approach while designing and building the system.

C. Critical Remediation

In Light is History, the LAD modules remediated the older electric meters by refashioning them and re-introducing new goals and functionalities. Here, the visual outcome was unfamiliar and 'both the past and the present media existed in a state of hypermediacy'.[18] This is used to display the inconsistencies between media in order to raise critical awareness. This 'Counter-Remediation' is key to a critical understanding of the problematics of energy measurements and visualization.

Table 6.7. Areas and Actions toward Critical Remediation

AREAS	ACTIONS	METHODOLOGY
Curating	co-curation	CRITICAL REMEDIATION
Digitization	open digitization	
Heritage Content	Community-sourcing, Remixing & Remediation	
Infrastructure	Remediation, Advanced Fabrication	
Software	Open Source	

Critical Remediation was the dominant idea in the design intervention at the Gallen-Kallela Museum. Media in the form of an old scanner marked the presence of an older media, but then becomes part of a new media system without completely disappearing. Here the old media is repurposed with enhanced functionalities, where the capabilities of the old media are not discarded. This approach allows to us to refashion old media that would otherwise be obsolete. By this, we are able to reuse the embodied energy of the media artifact, extend the life-cycles and thereby save natural resources in the long run.

COMPARATIVE ENERGY & EMERGY ANALYSIS 6.2.5

Although the museum and the design interventions cannot be compared on the same scale, an analysis based on energy and emergy show a vast difference in material and energy use. Here they have been compared to the Cooper Hewitt Museum, a typical residence and the Smithsonian data center.

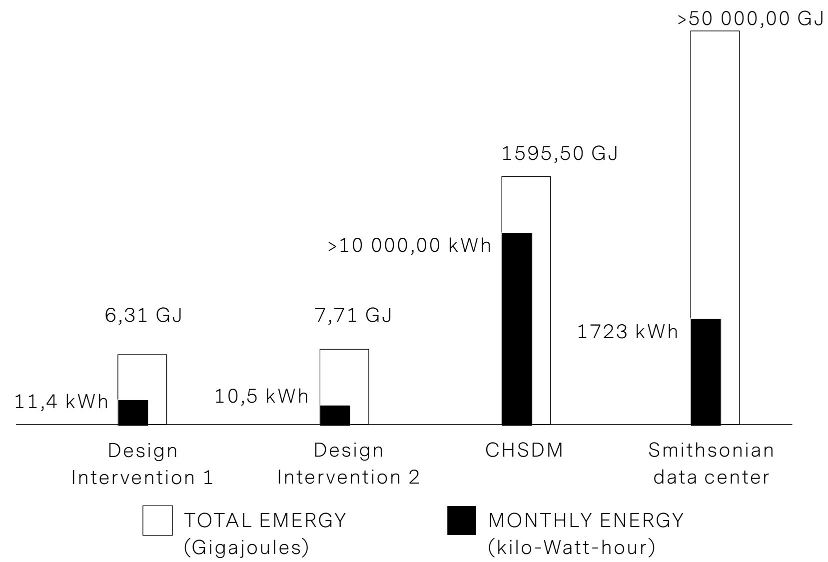

Fig. 6.2. Intervention 1 and 2 as compared to Cooper Hewitt Museum and Smithsonian Data Center in terms of energy use and emergy.

As shown in figure 6.2, the energy use of the Cooper Hewitt Smithsonian Design Museum is greater than 10 000 kWh and correspondingly the Smtihsonian Data Center's energy use is 1723 kWh. The energy use by Contemporary Art Museum Kiasma in Helsinki was 7953 kWh (February 2014).[19] The energy use of the design interventions are low and at similar levels (the calculations were made for 30 days consumption based on the hours of operations). As can be seen from the figure 6.2, the emergy of the data center is substantial at over 50 000 gigajoules (see 3.7). This is directly related to its massive media infrastructure that contains over 1000 servers, routers, HVAC and energy back-up systems.

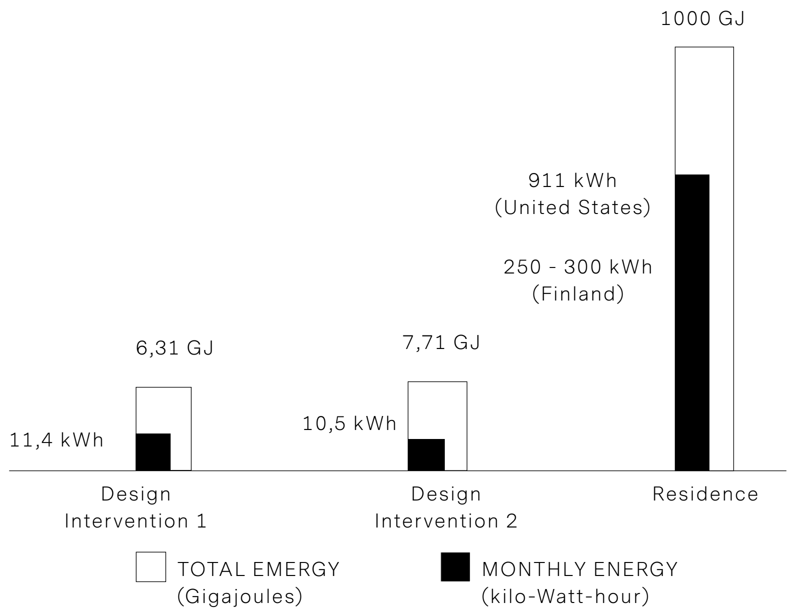

Fig. 6.3. Intervention 1 and 2 as compared to a typical residence in terms of energy use and emergy.

As shown in figure 6.3, the energy use of the design interventions is minimal when compared to a typical american residence (911 kWh),[20] or a home in Finland (250-300 kWh). A home has high emergy mainly due to the construction materials, the mining, processing and shipping of which takes a vast amount of energy.[21]

NOTE: In this study, to calculate the flow of content and corresponding energy use was not feasible, since it would have required energy monitoring separately each individual department. The Cooper Hewitt and the Gallen-Kallela Museum did not release their energy data that could have charted the energy flows within their institutions. Therefore this part of the study has been set aside for a future examination.

SUMMARY OF FINDINGS 6.2.6

The primary findings of the excavation show that the invisible media infrastructures of the museum are energy consuming and have high emergy. These are generally closed proprietary systems loaded with imminent obsolescence that are being utilized for digitization, representation and dissemination. These infrastructures are sequestered and hidden in the back offices of the museum and concealed from public view. Outsourcing of design and deployment of media infrastructure has limited the amount of in-house knowledge generation and expertise. Various components and departments of the museum stay separate and isolated in their own spheres of activities, in the process building scattered black boxes of knowledge and practices. As a result the museum is never able to foster active and vibrant communities, the personnel and the user communities being under-utilized in their potential as significant stakeholders.

The primary findings of the design interventions show that it is possible for a museum to design and build ecological media infrastructures in participation with user communities. These open systems and infrastructures do have disadvantages. They might be time-consuming and complex in their makings, yet they provide alternative experimentations that not only engages the museum's communities as participants, but builds a common shared knowledge and in-house expertise. Bringing the private back office to the front, revealing the invisible methods and infrastructures creates transparency and goodwill for the museum. Visibility of infrastructure has an impact on energy consumption, as seen in the design interventions. Here, the themes of energy and emergy were threaded into the activities and practices of the museum, allowing the institution to be engaged in a vital discourse. The interventions also showed that open access and knowledge could be integrated and fostered within these visible and tangible workings of the museum rather than releasing a million digital images into the Cloud.

6.3 DESIGN FRAMEWORK

By combining the research findings from the excavation, contextualization of the museum and the operative methodologies of the design interventions, the research establishes the design framework. The intention here is that the framework of concepts can assist museum personnel in participation with user communities to plan or revamp the media infrastructure of the museum.

6.3.1 SYNTHESIS

The design framework critically addresses the museum, combining at a primary level what Parikka calls 'the materiality of materials' and the 'materiality of technologies',[22] with Hertz's Critical Making,[23] and our own critical method of Bolter and Grusin's Remediation theories.[24] At a secondary level, it brings in energy and emergy studies and infrastructural evaluations that can provide further empirical basis for the methodologies derived, with an attention to the specific materialities behind the processes.

The Design Framework developed in this dissertation is overall critical and reflective, analytical and quantitative, when it comes to excavating, designing, making and deploying the various components of a media infrastructure. As discussed earlier, the methodologies are deeply materialist in orientation,[25] 'enumerative rather than narrative, descriptive rather than discursive, infrastructural rather than sociological, taking numbers into account instead of just letters and images',[26] but also incorporates within, the need to 'articulate non-narrative frameworks',[27] existing in the soft infrastructure that negotiates digital content.[28] Seen from this approach, the design framework is a composite methodology to address the material and energetic impact of the museum. As such, seen together, is a step toward a 'critical' form of 'materialism', a critical perspective of media, a reflective set of methodologies to study media and materiality critically in context of the museum.[29]

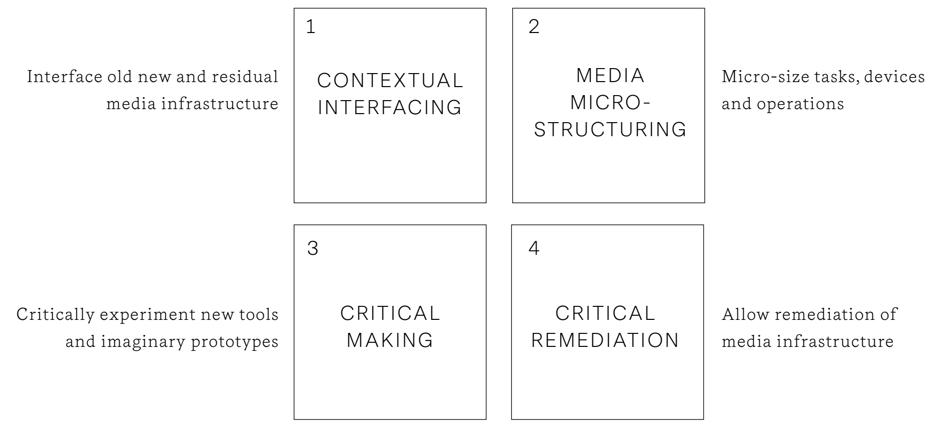

Figure 6.4. The Design Framework

Thus, as introduced in Chapter 1 (1.6), the primary concepts that emerged from the research are Contextual Interfacing, Media Microstructuring, Critical Making and Critical Remediation. (The areas, actions and methodologies from the findings have been charted onto a Table 6.8.)The first two deal with the 'in-housekeeping', shaping materialist identity and the others those are 'public-facing' those which embody materialistic actions with community and is future-facing. Contextual Interfacing and Media Microstructuring mainly deal with mapping and structuring the hard media infrastructure, with 'soft' overlaps, while Critical Making and Critical Remediation are performative, primarily dealing with reflective making, remediating both the hard and soft media infrastructure. Contextual Interfacing, guides how the museum interfaces with its infrastructure, its various materialities both new and residual to provide a unified view. Media Microstructuring then instructs how the museum plans and deploys its tasks, devices and operations in a scaled-down method that is suitable to the institution. Critical Remediation shows participative domains of the museum's media infrastructure where community could be tactically and reflectively engaged in the renewable character of media. Finally, Critical Making brings in the imaginary, where using a critical reflective approach, new tools, new linkages could be built within the museum that address media infrastructural issues.

Table 6.8. Charting areas, actions, methodologies to a design framework

AREAS	ACTIONS	METHODOLOGIES
Media Devices	Inventorying	CONTEXTUAL INTERFACING
Energy consumption	Energy Analytics	
Digital Collections	Collections API	
In-House Developments	Self-Publishing	
Facilities Management	Building Information Model	
Media Devices & Interfaces	Scaled, Collaborative, Open Source	MEDIA MICROSTRUCTURING
Daily Museological Tasks	Scaled, Prioritization, Shared	
Project Management	Co-production, Shared, Collaborative	
Community	Participation	
Curating	Co-curation	CRITICAL REMEDIATION
Digitization	Open Digitization	
Heritage Content	Community-sourcing, Archiving, Remixing & Remediation	
Infrastructure	Remediation, Advanced Fabrication	
Software	Open Source	
Curating	Co-curation	CRITICAL MAKING
Installation	Co-production, Co-design	
Energy Content	Self-Publishing, Archiving, Energy API	
Infrastructure	Reuse, Recycling, Advanced Fabrication	
Software	Open Source	

Thus, the four components of the design framework are Contextual Interfacing, Media Microstructuring, Critical Remediation and Critical Making. These guidelines show what planning and designing for media infrastructure would entail:

1. Interfacing all the media infrastructure, old, new & residual
2. Micro-sizing all tasks, devices and operations
3. Critically experimenting with new tools and imaginary prototypes
4. Allowing community remediation of media infrastructure

GOALS OF THE DESIGN FRAMEWORK 6.3.2

The goal of this design framework is to provide a set of methodologies that when followed could lead to an improved planning mechanism of the media infrastructure of the museum. In the same way diagrammatics as a framework may guide designers of digital media, as instructional and hence operational tool for excavating technical environments "(such as a diagram of connections between the technical components in that specific piece of media technology but also through how it opens up to external connections)",[30] the design framework acts as a guide for infrastructuring of the museum's media infrastructure. With regards to the stage of implementation, they are primarily to be acted upon at the planning stage, but could be utilized in other stages of the design and general operations of the museum. The aim is that by following all the components in the framework, the resulting media infrastructure will not merely be low energy consuming but also ecological.

DISCUSSION OF COMPONENTS 6.3.3

The four components of the design framework have been developed from the methodologies and principles discovered through this research's excavation of museum infrastructure and design interventions. There are overlaps between since it is impossible to utilize these concepts and methodologies independently without affecting the others. In the following, these are discussed and expanded upon.

1. CONTEXTUAL INTERFACING

In management information systems, a dashboard is "an easy to read, often single page, real-time user interface, showing a graphical presentation of the current status (snapshot) and historical trends of an organization's key performance indicators to enable instantaneous and informed decisions to be made at a glance."[31] Dashboarding is the act of constructing such graphical interfaces to provide a unified view. Interfaces that map the various components i.e. the hard media infrastructure of the museum are needed. This includes not only interfaces for in-house use but also for audience participation.

A. Inventorying

Interfaces with detailed archiving of the various media devices and networks of the media infrastructure, their specifications, operation manuals and accessibilities. This should include past and present, new and residual, their histories of usage, their problems and solutions. At a quick glance, one should be able to tell the whole media history of a media exhibit located in any one exhibition gallery, or the upgrading history of a certain networked device. Such inventorying would allow a deeper and longer perspective into device and network usage, save time and energy for users and managers. Inventorying all hardware media devices and exhibits of the museum, i.e.. the hard media infrastructure of the museum and collecting them in an archive. This diagrammatic archive would be "a central place for collecting and engineering technical media, a site of study in the same manner as the laboratory or the classroom."[32]

B. Energy Analytics

Interfaces that display several key energy usage parameters of the infrastructure through a customized application. The parameters should be daily global and local energy use, a breakdown of componential energy use, by rooms, by activities and operations. Energy footprints of dedicated short-term and long-term projects should also be visible.

Analytics should provide annual, monthly and daily comparisons, also between operations and activities, between internal local media infrastructures.[33] Constant monitoring, tracking is essential to energy consumption since it makes the processes open to enquiry thus operational knowledge is acted upon and enhanced.

C. Collections API

An API is a quintessential requirement for any museum with digital collections. This key infrastructure allows a museum to centralize and propagate its digital collections and resources. It provides the database and methods to build web applications on top, install collection tracking, visitation data and ticketing and provides granular control of the collections. A well-built museum API lets third-party developers to negotiate the data and build applications . An API also opens up possibilities of data visualization for artists and researchers. In the long run, a museum API promotes long term viability of the collection, digitization and exhibition processes of the museum. It reduces repetitive curatorial activities since there is global control of the collections, since ideas can be already tested and prototyped through programming. An API is also the significant link between the digital collections, artifacts in storage and media exhibits on the floor of the museum.

D. Self-Publishing

The already existing knowledge community within the museum, the in-house personnel, should be able to share and publish their thoughts, experiments, updates and practice-based solutions for others to see. Discussion within an online museum forum can benefit the operations of the museum. New ideas and prototypes built can be demonstrated and commented upon. Files and presentations can be shared and conversations enabled. A layer of the discussion can be made available to the museum audience. In-house publishing can save time and help solve daily operational problems and this in turn encourage responsible museum practices.

E. Museum Information Model

By combining the collections API of a museum with its BIM and 3D model, digital collections could be synchronized with the media history of the architecture, the physical exhibition and conservation spaces, resulting in a collaborative digital ecosystem. This combined tool could examine a museum's energy use as they relate to maintenance and exhibition of the collections. Further, it also could determine the extent and engagement of a community with a museum's collections within the context of the physical structure.

2. MEDIA MICROSTRUCTURING

Through the outcomes of the design interventions, a methodology of 'Microstructuring' media was discovered. This refers to scaling down of devices, tasks and operations that are part of the hard media infrastructure. It also pertains to project management and building participative projects with museum communities.

A. Media Devices & Interfaces

Microstructuring could happen in the scaled down media devices and networks that are part of daily museum's daily digital operations. It can also happen in selected speculative experimental projects and prototypes. For example, as seen in the design interventions, Microstructuring digitization devices could be suitable to small museums and archives.[34] It could assist them when funds and trained personnel are limited. Microstructuring can also change the scales of media operations of a museum and provide technical alternatives for heritage conservation. Through smart, modular and minimal interface design and micro-scaled open source web applications and archives, the museum could save time and resources leading to efficient utilization of resources.

B. Museological Tasks and Practices

Daily in-house activities such as curatorial, conservation, operations, publishing and marketing could benefit from the micro-scaling. Digital asset management could focus on small, simple tasks of handling metadata, adding new artifacts and publishing on a daily basis. The backend of collection software could be micro-structured for efficiency as seen in the strategies deployed at the Gallen-Kallela Museum. Archiving can also happen in small packets of daily tasks. The scale of the digitization can be reduced by a prioritization of the size and quantity of artifacts relevant only for current purposes.

C. Project Management

Microstructuring projects could assist and benefit the museum's media infrastructure on several fronts. It could streamline the project management to deploy projects and exhibitions on time. This involves efficiently micro-scaling, organizing and sharing communications, design research, curating, digital asset management, programming, making (building) and logistics on a tight time schedule. By scaling down and sharing work related to guidelines for participation, benchmarks for artifacts, specifications and feedback processes in a manageable scale and format could benefit small teams and smaller institutions.

D. Participation

Microstructuring can enhance community participated projects in the museum. Since it limits and focuses on a smaller range of issues, content and actions, commitments and stake-holding to projects and events can be easier to gather and consolidate. Such events have the potential to mature into community Contact Zones.[35] Content distribution through micro-structured events, open source devices and interfaces can be simpler to coordinate in community-participated events. Microstructuring provides a clarity of engagement to the museum personnel and the participants simply by encouraging small packets of engagement supported by small media infrastructure. Finally, as demonstrated in the design interventions and countless literature on the subject, smaller systems and processes are by their very nature low energy-consuming.

3. CRITICAL MAKING

Critical Making primarily deals with both the hard and soft media infrastructure, especially critical experimentation with the design and construction of new tools and prototypes. The approach is to test new strategies in context of the museum, to learn and know the tools and infrastructure.This can also be termed as Contextual Making, where new museum tools and prototypes are reflectively made in context. A 'Making' that is open-ended, non-specific and encourages adaptable processes. This is so that energy use and embodied energy of media infrastructure is understood from the very beginning of creation within the working community of the museum. Then, it can be further tested among the museum audience and then, the general community. By this, the museum is able to gain new ecological media tools and processes. It is also able to enhance its capabilities to amplify its collections, gain new knowledge and expand stake-holding. A particular example of Critical Making in the museum would be to make speculative artifacts to test energy use and technological obsolescence.

A. Prototypes / Installations

Critical Making of hardware prototypes, media exhibits and installations in context at the museum can be an ecological method in the long term. The in-house museum community are at an advantage when it comes to knowledge about the media infrastructure of the museum. This knowledge can be advanced by designing and building prototypes in collaboration with other institutional research partners in academia or independent research units. Here, the materiality, practicality, connectivity, interoperability and longevity of the media used and made can be easily tested and implemented before they are deployed. The whole project thus in itself gains a 'time-critical' aspect, i.e. within realistic time frames and budgets.

B. Web Tools

Experimental tactical applications can be designed and built on top of the Collections API. Using a ready API database and methods, a museum can efficiently program new applications in the fields of collections management, ticketing and visitation and novel approaches to digital engagement with collections. A Critical Making approach lets the makers within the museum pursue a reflective strategy in designing applications, that they are made, tested, reconfigured and retested and so on, taking into account changes and feedbacks into the process of making before allowing third-party developers into the scene. This method also allows artists and researchers to fork and develop a web tool into other strands of the media infrastructure. Thus, new knowledge is created on several levels that can feed into the long-term objectives of a museum.

C. Digitization Tools

Today, digitization of collections is a significant necessity for especially a heritage museum. Digitization equipment can be expensive and usually needs a huge investment in hardware and software. Instead of outsourcing the tasks, building a customized contextual digitization equipment can be a responsible investment for a museum. This allows the museum to shape the digitization processes based on the nature of its collections.

D. Speculative Tools

A museum can be considered as a lab for experimentation and prototyping, it is a safe place for unsafe ideas. Speculation in materials, devices, methods and processes in the field of curation, heritage conservation, exhibition can augment the museum experience. Such tools or devices can be both hardware and software, could be used both internally and externally with the museum audience.

4. CRITICAL REMEDIATION

Critical Remediation deals with both the hard and soft media infrastructure, the application programming interfaces and digital archives. It puts into action participative domains of the museum's media infrastructure where community could be tactically engaged in the residual and renewable character of digital media. Reflective participation is a key factor in environmental practices of the museum.

A. Curating

A domain that is traditionally the fundamental internal anchor of the museum might be the one that is also the achilles heel of the museum. Here, the process has always been invisible to the audience and as well the resources that go into it. Co-curation with the museum audience and the community could open up this domain for participation and remediation. As found in the design interventions, the entire process of co-curation could simulate the workings of a research lab being both experimental and interdisciplinary.[36] Here, remediation could involve both hacking the digital collections through the API and as well as repurposing them into alternative online exhibitions. Although coordinating participation would incur human resources, the power of the online community could be utilized tactically in the daily practices of the museum.

B. Digitization

Remediation of collections by the community through digitization of community-contributed artifacts could benefit the museum and in general cultural heritage collections. By microstructuring digitization, the material processes of translation between tangible collections and digital artifacts can be minimized. By foregrounding the invisible infrastructure of digitization in the public museum space, participation, feedback, alternatives, approaches could be enhanced. The energy footprint of digitization can be displayed openly, as demonstrated at the Gallen-Kallela Museum providing the audience with a possibility of reflection and the museum with an opportunity to display responsibility in its otherwise internal processes.

C. Archiving

Community can be a critical vessel for reflective remediation of collections. Since archives are discontinuous, ruptured and form relationships through networks,[37] and correspondences, it is ideally suited for participation by community. Since an archive is a place for recovery too, not only unpublished artifacts could be harnessed, but also re-interpretation of archival materials through multiple points-of-view can add a depth of context. The remixing of archives by museum audience as demonstrated in the design interventions could invite new unknown history, unfamiliar culturally-vital outcomes, without the museum itself spending resources to gather that data. In some cases, the remediation mechanism could be ecological than the mere vitrine display of an artifact. Re-interpretations into real life and repurposing of digital collections in an archive can generate further engagement.

D. Productions

Participation in the museum's productions amplifies the collections of the museum and has a direct effect on the soft media infrastructure. It hands over control of the public face of the museum to the audience, in other words, here the API, the media exhibit software, the algorithms can be put into play, negotiated and acted upon. The community could be tactically engaged in co-production, thus reversed from consumption to a state of critical reflection.

6.3.4 SUMMARY

Our design framework guides museums, architects and media designers to build ecological media infrastructures. Our goal is to use material forms of engagement with technologies to supplement and extend critical reflection about energy and environment. By working with the four core methodologies of our framework, they can create tools and initiate processes towards the design of media infrastructures.

The four primary methodologies of the framework: Interfacing, Microstructuring, Making and Remediation are instrumental to analyses, design and construction. Contextual Interfacing encourages exploring the museum's own identity, its mission, existing infrastructure and the nature of its collections. Media Microstructuring pushes museums to micro-scale their media, share tasks and open up processes. Critical Making and Remediation are the methodologies by which the museum explores new ground through reflective building of prototypes, designing processes and remediating collections.

Together they should be regarded as tools for further critical examination of the media practices and infrastructure of the museum. It would be futile if each component of the framework was solely followed without critically practicing the others, since all of them feed into each other, spill over and in some cases redundantly so. Interfacing the media of the museum could be followed up by Microstructuring, Remediation could be incorporated into Making. Besides, all other methods within the methods themselves are necessary to be evaluated if not utilized since they do not provide complete and closed models of media infrastructural development. Instead, the methodologies within the framework are meant to be open-ended, that they be critiqued, localized and customized by all responsible stakeholders.

6.4 CONTRIBUTIONS

The dissertation presents three main contributions. First, a methodology to excavate and design media infrastructures as described in 2.5. Second, two novel open source systems in chapters 4 and 5. Finally a design framework as discussed in 6.3. developed as a set of design methodologies for building ecological media infrastructures to serve museums.

MEDIA INFRASTRUCTURAL METHOD 6.4.1

The dissertation advances a novel system of methods, that comprises of two parts: first, the excavation of the museum's media infrastructures and second, the methods used to conduct design interventions. Excavating the museum comprises of contextualization, excavation of infrastructure and system diagrams / diagrammatics. The methods are used to examine the various media components, operative frameworks, relationships and to conduct infrastructural energy and emergy analyses. Contextualization looks at the historical and contemporary state of media infrastructure. Mapping the museum infrastructure facilitates an understanding of the visible and invisible infrastructures that are related to energy consumption and energy embodiment opening up avenues to conduct design interventions. Another varied set of methods are applied here ranging from constructive design research to reflection-in-action, from critical making to circuit bending. These multi-disciplinary methods when adapted and customized to a particular museum system could assist the design and construction of novel open hardware systems and software. Seen together, these methods comprise a toolkit to conduct a thorough examination and design of a museum's media infrastructures.

NOVEL MEDIA INFRASTRUCTURES 6.4.2

Novel hardware systems along with customized software resulted from the design interventions especially aimed at museums and cultural heritage. These systems have well documented open source code and freely available and easily adaptable 3D design files. Not only are these designs accessible and participative, but they are also simple to fabricate, assemble and deploy. Both systems are low energy consuming and contain little embodied energy. The dissertation has provided extensive descriptive and technical details of both the design interventions with links to the source codes and design files. As such, these systems can be easily adapted and integrated into existing museum infrastructures.

6.4.3 DESIGN FRAMEWORK

One of the primary contributions of the dissertation is a Design Framework as discussed in 6.3. developed as a set of design principles for building ecological media infrastructures to serve museums. These are approaches that emerged during the course of the study. They are primarily to be acted upon at the planning stage, but could be utilized in other stages of the design and general operations of the museum. The framework targets the museum personnel and user communities as the primary stakeholders. Although not evaluated by real projects yet, the framework could serve as a critical and exploratory toolkit for museums and designers in the future towards building intelligent and responsible museums. It can assist museum personnel in participation with user communities to plan or revamp the media infrastructure of the museum.

6.4.4 SUPPLEMENTARY CONTRIBUTIONS

While the design framework was the primary aim of this research, several other contributions can be considered as significant outcomes. This research presents not only new knowledge, data, approaches, and methodologies which can be useful to researchers in the field of Media Studies, Design, Museology, Architecture, Computer Science and Engineering, but also advances new studies and data related to the specific study into energy-consumption and emergy. As such, new methods and approaches to examine infrastructure and related energy use are also presented. Complementary to the design framework, the design interventions in chapters 4 and 5 present a novel approach in exploring energy use and emergy of media infrastructures. New energy saving strategies have developed from within the design interventions that could be utilized for future evaluations.

CHALLENGES 6.5

MULTI-DISCIPLINARITY 6.5.1

This study lies at the intersection of several disciplines all of which is not possible to master in the limited timetable of doctoral studies. Although the design interventions benefit from collaborative teams, there was not enough representation and inputs from other fields. The design interventions could have benefitted from researchers and experts from electrical engineering, mechanical engineering, electronics, service design, robotics, and energy studies. Thus, the study may have gaps in its findings. As such, the final design framework is intended to be a preliminary critical and exploratory toolkit that needs further development for maturity.

SPECIFIC MUSEUM SYSTEM 6.5.2

This study has limited itself by focusing on the single museum system of the Cooper Hewitt Smithsonian Design Museum and through the second design intervention, the workings of the Gallen-Kallela Museum. Ideally, the research could have been conducted with other museums in different geographical, economic and cultural settings. The Cooper Hewitt represents merely a microscopic fraction of the world's cultural heritage. Yet, within the time frame of doctoral studies, (considering the amount of design and documentation that goes into an extensive case excavation and two design interventions ranging from 2011 - 2015), it was not feasible to conduct a broad ranging study of museum systems around the world. Hopefully, the next exploration would become part of the future work while evaluating and developing the design framework.

ENERGY AND EMERGY DATA ANALYSIS 6.5.3

First, energy and emergy data is hard to come by and second, analysis of it requires complex mathematical processes. Since, energy consumption falls under the domain of private data, there is an extra hurdle of obtaining permissions and signing disclaimers. In both the excavation of the museum and the design interventions, obtaining energy data was a difficult and tedious process. Especially in a museum institution, obtaining energy meter readings is close to impossible without much promises, commitment to privacy etc. Energy providers are equally unwilling to cooperate in research studies citing national security concerns. The same goes for securing data from community participants and museum audience. All the above require a long list of documentation and waivers. Finally, the energy analysis themselves are intricate, granular and require sorting through a plethora of scientific methods. In our energy and emergy calculations, we have tried to simplify the process, so that we could reach a general estimate. As of 2015, there were no single authoritative data sources on the energy and emergy of media infrastructures that we can rely upon. As such, the energy analysis are merely meant to be indicators, to raise awareness about the problem.

6.6 FUTURE WORK

6.6.1 EVALUATION OF DESIGN FRAMEWORK

The design framework needs a comprehensive evaluation for it to become a mature and dependable set of methodologies. Although the methodologies themselves are derived from documented studies and design interventions, they have not been tested holistically in a single museum system. The infrastructural energy analysis also needs further research and input from energy experts and experiments.

6.6.2 FURTHER STUDY OF MEDIA INFRASTRUCTURE

The 'deep time' of museum (media) infrastructure needs further research and could be one of the first places to expand the study in the future. Here its long-standing relationship with architectural and urban history needs investigation. The study could explore the history of the museum as media infrastructure, the rise of interpretive media in museums and the energy-crossroads that the museum is currently facing. This would be accompanied by an extended analysis of 'hard' and 'soft' media infrastructures that support collections in museums and within it the energy life of an artifact.

6.6.3 MATERIALITY AND OBSOLESCENCE

An avenue of future work would be to critically frame digital obsolescence and how it would affect museums and media infrastructure in terms of energy use; to invite critical reflection on material practices – "contributing to unchecked digital content production and the almost unnoticed or assumed eventual obsolescence and disposal of everyday digital devices."[38] The design framework of this study could be utilized to develop speculative ecological media artifacts that challenge digital obsolescence creeping into the infrastructure of museums and heritage institutions. How materiality, energy use and obsolescence would be affected by an alternative mode of operations of the museum resulting from using such speculative artifacts?

6.6.4 DIGITAL MEMORY, ENERGY AND ECOLOGY

A future research challenge would be to uncover the environmental burden carried by digital memory. Especially, to understand the nature of memory today as fostered by the media-intensive museum. How does computational memory, embodied memory of materials and energy, and the memory embedded in archives and born-digital collections together form a composite infrastructural memory? What are the ecological impacts of 'mediatization' of memory and the impact of the environment on memory itself?

6.7 CONCLUSION

The dissertation presented here has attempted to addresses the challenge of the Post-Oil Museum (1.3). The ideas of small scale, low energy infrastructures combined with critical thinking, making and mediation in context of museums and cultural heritage have been carried over, developed, and matured in the course of this study. While there remains potential for other cross-disciplinary approaches, the study has remained focused on the central underlying idea that the materiality of the medium shapes the outputs, the flow of content - the message of the museum.

The methodologies adopted in this study point to a critical approach to the materialities of media infrastructures. Through a brief 'deep time' excavation, contextualization and design interventions, the study attempted to understand the origin, growth and contemporary expansion of the media infrastructures of the museum. By excavating the past and the present and understanding the museum system, components, operations and energy use we traced the nodes and points within the infrastructure is related to high energy use and emergy. Then through a series of design interventions we have attempted to address the infrastructural-energy issues and sought to find alternatives. We identified areas of shortcomings and benefits learned from the excavation of the museum system and the design interventions.

Through the above processes we have formulated a Design Framework that illustrates a novel and critical means of infrastructuring for museums. The framework's four components: Contextual Interfacing, Media Microstructuring, Critical Making and Critical Remediation provide a set of guidelines, facilitate analyses, design and construction in the field of media infrastructuring of the museum. These concepts or methodologies should be regarded as tools for further critical speculation and not as providing complete and closed models of media infrastructural development. Instead, these methodologies are open-ended such that it is possible to be acted upon by others.

In this era of global warming, obsolescence and technological breakdown, the study has attempted to address a critical gap in museum and media infrastructure studies. It has emphasized that the cultural impact of the museum can also be sustained through ecological actions, from "the larger, faster and more centralized, to the smaller, slower and more local; from competition to cooperation; and from boundless growth to self-limitation."[39] Today, media infrastructures of not only the museum but the entire planet are growing at a frightening speed which threatens to swallow our natural resources and leave gigantic holes in the ground and in the atmosphere. Further media studies, design experiments and infrastructural interventions are needed to completely understand the scope of the problem and provide alternative paths to ecological media infrastructures.

NOTES TO CHAPTER SIX

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3 Sean Cubitt, Ecologies of Fabrication in *Sustainable Media,* , ed. Nicole Starosielski and Janet Walker (London: Routledge, 2016),163-178.

4 Maughan, "The dystopian lake filled by the world's tech lust."

5 Parikka, *A Geology of Media.*

6 Parikka, Jussi, introduction to Digital Memory and the Archive by Wolfgang Ernst (University of Minnesota Press, 2013), 8.

7 Ibid., 8.

8 Parks and Starosielski, *Signal Traffic: Critical Studies of Media Infrastructures*, 5-6.

9 Druckrey, Timothy, foreword in *Deep Time Of The Media: Toward An Archaeology Of Hearing And Seeing By Technical Means* by Siegfried Zielinski (Cambridge, MA: MIT Press, 2006), viii.

10 Parikka, Jussi, introduction to *Digital Memory and the Archive*, 7.

11 United States Copyright Office, U.S. Copyright Office Fair Use Index, last updated February 2016, http://copyright.gov/fair-use/ (accessed February 16, 2016). Fair use is a legal doctrine that promotes freedom of expression by permitting the unlicensed use of copyright-protected works in certain circumstances.

12 The museum had 73771 in-person visitors already in First Quarter of 2015 (Smithsonian 2015) versus an average of 50000 visitors in the First Quarter of 2011. It had a monthly online visitation of an average of one hundred thousand visitors (568159 Website visitors in FY2015 and counting), half a million page-views from over a hundred countries worldwide.

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17 Hertz, *Critical Making: Introduction.*

18 Bolter and Grusin, *Remediation: Understanding New Media,* 44-50.

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20 U.S. Energy & Information Administration, FAQ, https://www.eia.gov/tools/faqs/ (accessed March 24, 2016).

21 Geoff Milne, Embodied Energy (updated 2013), http://www.yourhome.gov.au/sites/prod.yourhome.gov.au/files/pdf/YOURHOME-3-Materials-1-EmbodiedEnergy-(4Dec13).pdf (accessed March 24, 2016). Research by CSIRO has found that the average house contains about 1,000GJ of energy embodied in the materials used in its construction, see: http://www.csiro.au/en/About (accessed March 24, 2016).

22 Jussi Parikka, "New materialism as media theory: Medianatures and dirty matter," Communication and Critical/Cultural Studies 9, no. 1 (2012): 95-100, doi: 10.1080/14791420.2011.626252 (accessed March 22, 2016); Jussi Parikka, *What Is Media Archaeology* (John Wiley & Sons, 2013), 159-167.

23 Hertz, *Critical Making: Introduction.*

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25 Gane and Hansen-Magnusson, review of *Optical Media* by Friedrich Kittler in Theory, Culture & Society Vol. 23, 7–8 (2006): 315–328.

26 Ernst, "Media Archaeography: Method And Machine Versus History And Narrative Of Media," 239-255.

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29 Our thinking of 'Critical Materialism' is not unique. In 2010, York and Clark in a sociological study contend that a critical scientific materialism is needed to understand and address environmental crises. They say: "The goal of a critical-materialist science is to provide a sophisticated understanding of the organization of the world, one in which the scientific process is demystified and transformed to encourage critical questions about the historical realities we confront….the concept of environmental sustainability demands that we take a realist position in regard to the material world. Through scientific inquiry we can gain an understanding of natural history, natural processes, and natural cycles, as well as the social forces that are transforming the world." See Richard York and Brett Clark, "Critical Materialism: Science, Technology, and Environmental Sustainability," Sociological Inquiry 80, no. 3 (2010): 475-499, 10.1111/j.1475-682X.2010.00343.x (accessed March 24, 2016).

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37 Ernst, "Does The Archive Become Metaphorical In Multi-Media Space?", 105-123.

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39 Heinberg, "Back to the Post-Oil Future.

APPENDICES

MUSEUMS & GREEN ICT STUDY:
Questions

INTRODUCTION

Q1 Can you tell a bit about your role and responsibilities at the museum?

UNDERSTANDING OVERALL ENERGY CONSUMPTION

Museum energy consumption

Q2.1 Does the museum monitor its energy costs (for example energy bills) over time (e.g. monthly, quarterly or annually)? Can you tell a bit about how it does that?
Q2.2 Are energy bills paid out of the museum's overall budget?
Q2.3 Does the museum track its energy consumption over time? (For example electrical usage is often measured in kilowatt-hours.)
Q2.3.1 Does the museum make a breakdown of any energy costs or consumption according to the type (electricity, lighting, A/C, Humidification, heating, computing)? If so, what are the relative sizes?
Q2.3.2 Is information technology a significantly large part of the energy costs?
Q2.3.3 Has the museum ever monitored energy consumption of any its IT equipment (computers, displays, projectors, etc.)?
Q2.4 Does the museum's own staff maintain the building's facilities?
Q2.5 How much of the museum's space is used as public exhibition space, versus private office space, internal operations, etc.?

Sustainability planning

Q2.5 "Sustainability" is a concept meaning to have a goal of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance. Does the museum have any formal planning for improving the sustainability of its operations?
Q2.6 Does the museum (e.g. management board, annual plan) set annual targets for reducing energy consumption or costs? How are those targets tracked?
Q2.7 Does the museum consider power consumption when buying new equipment?

UNDERSTANDING DIGITAL MEDIA ENERGY CONSUMPTION

Digital media exhibits

Q3.1 How many "digital media" exhibits (exhibits using large screens or projectors) does the museum have running / shown annually?
Q3.1.1 How long do they run for on average? (weeks? months? longer?)
Q3.1.2 Which is used most often: large screen displays or projectors?

APPENDIX 1

Digital media storage

Q3.2 Does the museum digitize and store digital pictures (or 3D scans) of any museum artifacts?
Q3.2.1 How are the digital copies stored? on tape? on hard disks?
Q3.2.2 Are the digital copies stored in network/cloud storage?
Q3.2.3 How many items totally in the digital collection now?
In number of items?
In gigaBytes of diskspace?
Q3.2.4 How many new items are digitized and stored per year?

Web presence

Q3.3 Does the museum regularly track its web traffic statistics? How much web traffic (e.g. GBs) was there over the last year?

Ending

Q4.1 Do you have any final thoughts or questions?
Q4.2 Do you think there are any important questions or topics for you, that were not asked?

1 .Poster

2. Participation Form

PARTICIPATION FORM

Light is History, is a community based energy art space. It is a proposal for creating a public art installation using domestic energy usage information and electrical artifacts from the participants' homes and connecting it with bright light therapy lamps in a public space. This project is planned during the autumnal month of November 2012 in the Kallio neighbourhood in Helsinki, Finland. It wishes to explore matters of collective well being, domestic energy usage and the cocreation of public space.

To participate in the project, please fill in the form below. Or for more queries get in touch with: samir.bhowmik@aalto.fi ; karthikeya.acharya@aalto.fi

As part of a community art project are you willing to share your home electricity reading with us for one week, just once everyday?*
· Yes
· No

Are you willing to loan us one small object from your home that requires electricity to use for the art project? *
· Yes
· No

Do you have your electricity meter located within your apartment that you can see everyday? *
· Yes
· No

Is Helsingin Energia your energy service provider? *
· Yes
· No

Do you carry with you a smart phone with internet access or a phone that can send SMS?*
· Smart phone with internet access
· Normal phone with SMS

Please share with us your name, location address, with building number and street number in Kallio, Helsinki, Finland. Also please write your email so that we can get in touch with you in the future:

Please hand this back to us.

3. Data Consent Form

Data Consent Form

Thank you for agreeing to take part in the Light is History project. I hope you find it to be fun and an interesting experience. The aim of the study is to gain a greater understanding of the way in which you live your daily life relating to energy use and your well being.

We will record our interactions and gather data using images, digital content like your daily energy consumption which you send us and hand written notes for production and later analysis. All data obtained from this record can be made anonymous if you wish to, before being published.

All data (including all digital content and notes) will remain safe and secure with the research team.
Use of the material will be restricted to research and for publishing as articles, conference proceedings or in journals.

[redacted]

Signature of Karthikeya Acharya and Samir Bhowmik

If you are willing and agree upon using an extract from your session and/or remain anonymous then please tick the following boxes:

- [x] I am willing for still images, video and audio extracts of me to be used.
- [ ] I wish to remain anonymous.

Name: [redacted]

Address: [redacted]

Date: [redacted]

I have been informed about the aims and procedures involved in this research. I reserve the right to withdraw at any stage in the proceedings.

[redacted]

Signature of the Research Participant

4.Instructions Sheet

PARTICIPATING INSTRUCTION SHEET FOR OF LIGHT IS HISTORY

To participate in this community energy art space installation you will need to perform two requests which are elaborated here. The first dealing with sending your input to light the bright lamps you will need about five minutes of your day to be spent online from the 21st November till the 1st of December, The second one is simple, you do it only once in the beginning.

1. FOR THE BRIGHT LIGHT THAT CONVEYS YOUR DAILY ENERGY USE

1) Since you are a Helsingin Energia customer, we will open an account with Sävel service to meter your daily energy consumption. You would need your Customer number and (Supplier's)Metering point ID number for this. You can find this on your Helsingin Energia bill. This is just for the first time to create an account.

https://www2.helen.fi/raportointi/

With this service you are able to view your daily energy consumption that takes place on an hourly basis. (Note: The service is not live, but gives in the values of the previous or the day before values)

2) After you have registered the first time, then once a day sometime in the morning you will have to login to the service, and check your value for the day for which the data is available and make a note of the value (the previous day or the day before depending on how they update the service).

OR

If you find it cumbersome and then you do not mind, allow us to access this data, for which we will create a temporary password till the period of the installation after which you can change the password and make it secure for you again.

3) After you have checked your value and know how much you have consumed in a day, send this to us through the our internet application on your phone or on the PC through the website on your browser sometime before noon. Thats all!

Electrical Data reporting begins on 21.11, preferably before noon.

4) Your data as a value will reach a MYSQL database on secure server.

5) The server will send the value to the installation at Hakaniementori.

6) If you have consumed less the previous day then it will light brighter, if you have consumed more then it will light dimmer.

7) Thus the installation questions if you are willing to consume less electricity in your home to light up the lamp to function as a therapy lamp and promote the well being of the general

public who walk around the Tori from 17.0019.00 o'clock everyday for one week.

8) We invite you to the Tori and come visit the place anytime from 17.0019.00 o'clock to have glöggi and coffee and also participate in the collective well being through the lighting of the lamps. Dress warm and bring in a cheer to the public space!

All data as part of this community art project will be secure

2. FOR THE OBJECT / ARTIFACT

1) What is your favorite object that needs electricity to function? Provide an image of that object or if possible the object itself. The image / object will be placed in the installation (size: 75 x 75 mm) , aiming to anonymously represent you in the public place along with your lamp which will convey your daily energy use with its brightness.

2) You are also requested to write a few sentences like a small story about the object, its power consumption as you know it and your relationship with the object. If this object/ electrical artifact could become obsolete in a postoil future due to an energy crisis or such environmental issues, what is it that you will miss about the object?

Please lend us your object / artifact OR, image of the object / artifact by 19.11. Also, email us your text narrative by 19.11.

I. Participation Form

DRAFT PARTICIPATION FORM – THEME DAY 9.2.2014 / 9.3.2014 / 26.4.2014

HALOO AKSELI ID N:o ____________________
Gallen-Kallela Museum
9.2.2014

ABOUT THE PROJECT, WHY ARE WE COLLECTING ARTIFACTS?

The Gallen-Kallela Digital Archive aims to collect micro-historical pieces of information connected to Gallen-Kallela and his network of friends, colleagues and acquaintances. This includes photos, texts and quotes from the museum's archives – as well as pictures, memories and stories that are brought to the museum by the visitors of the Theme Day. This project allows the collection of cultural heritage artifacts associated with Akseli Gallen-Kallela through community. The project also opens up the digitization and tagging process of historical material to the public. The digital phonebook archive will be sited in the Public Domain under a Creative Commons License.

RIGHTS INFORMATION
CC0 1.0 Universal (CC0 1.0)
Public Domain Dedication
The person who associated a work with this deed has dedicated the work to the public domain by waiving all of his or her rights to the work worldwide under copyright law, including all related and neighboring rights, to the extent allowed by law.

You can copy, modify, distribute and perform the work, even for commercial purposes, all without asking permission.

OTHER INFORMATION
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· Unless expressly stated otherwise, the person who associated a work with this deed makes no warranties about the work, and disclaims liability for all uses of the work, to the fullest extent permitted by applicable law.
· When using or citing the work, you should not imply endorsement by the author or the affirmer.

SIGNATURE AND NAME:
____

LET ME KNOW WHEN MY ARTIFACTS ARE UPLOADED TO THE DIGITAL ARCHIVE

Email address: ______________________________________

2. Story Submission Form

ID N:o____________________

MEMORY, STORY OR OTHER

PEOPLE INVOLVED

DATE

KEYWORDS

OTHER

APPENDIX 3

3. Artifact Submission Form

ID N:o____________________

OBJECT TYPE

DATE

MATERIAL

SIZE

USE

PROVENANCE

PEOPLE INVOLVED

KEYWORDS

OTHER

4. A5 Sketching-Scanning Card

ID N:o______

Haloo Akseli!

Nimi____________________
Ikä______ **Päivämäärä**____________
Ketä kuva esittää?

Piirros lisätään Haloo Akseli!
-verkkoarkistoon.

halooakseli.fi
www.gallen-kallela.fi
sysrep.aalto.fi/digglam/
facebook.com/gallenkallelanmuseo
instagram.com/tarvasp

#halooakseli

GALLEN-KALLELA MUSEUM
(SOURCE: DIGGLAM PROJECT NOTES 2013-14)

5 .System Concept by Verna Kaipainen (distributed under a CC BY-SA 3.0 license)

Concept in Brief

The key ideas behind my design concepts are feasibility, simplicity and to highlight the most important parts in the big picture.

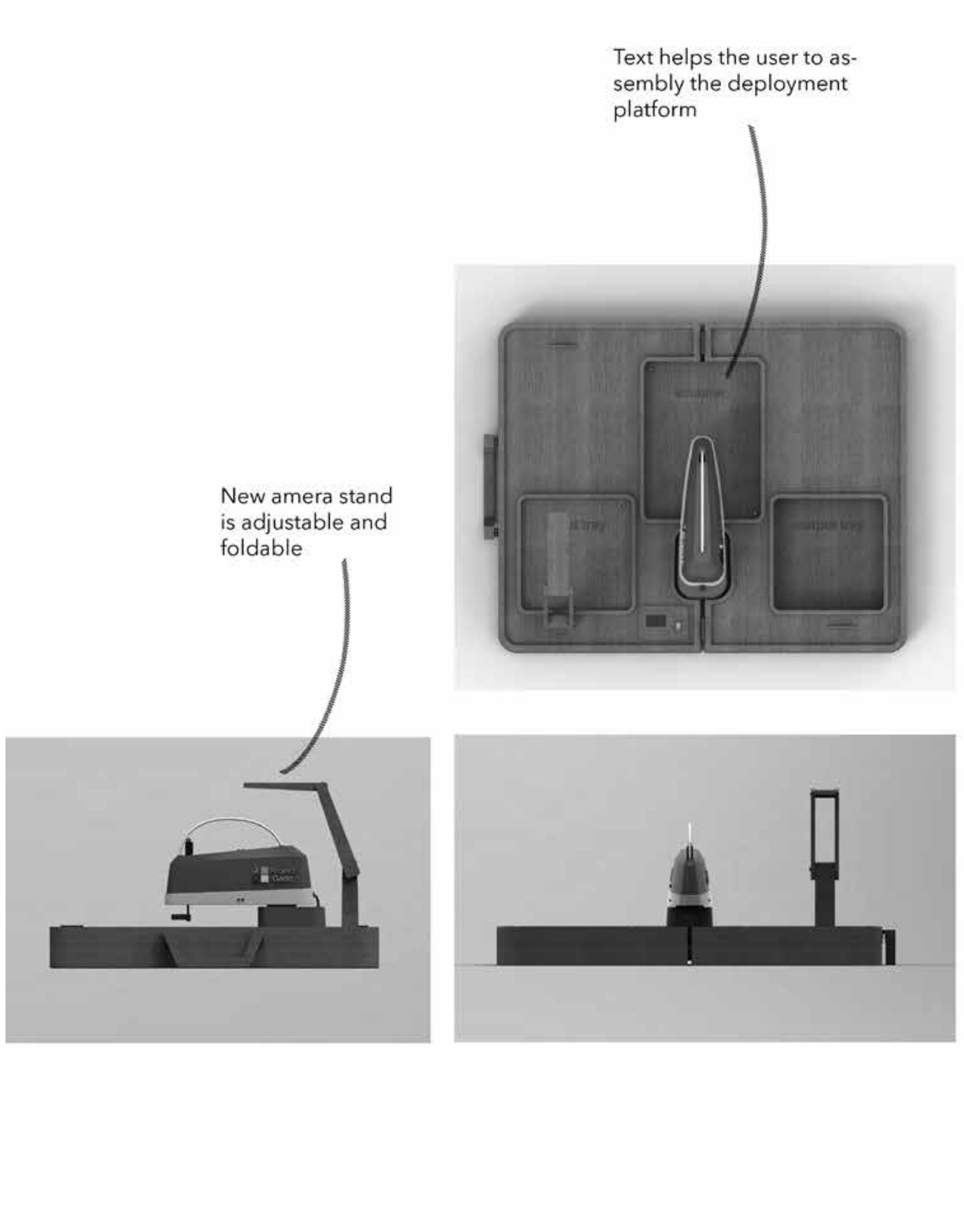
As I saw it the visually most challenging part in the DigGlam Assistant was the amount of cables that made a messy and unorganized look for the robot and deployment platform. In my design I tried to organize and cover the cables so that the user and audience (in different venues:museum, pilots,test days,demos etc.) can focus their attention on the actual process of the automated scanning of the documents.

I used highlighting colors and text to make the process of assembling/ deassembling the robot and using it for scanning would be easy for everyone to do.

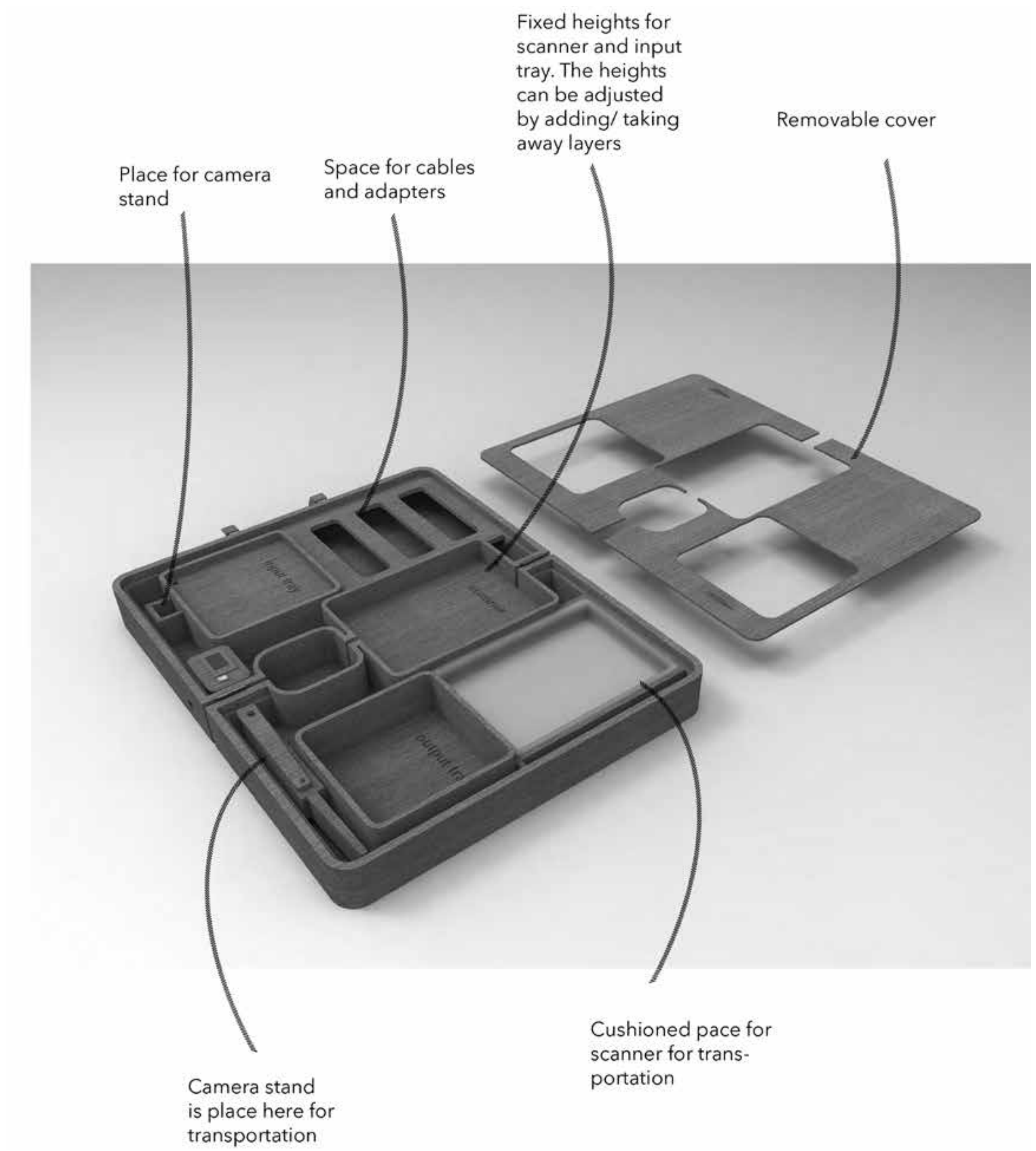
I also wanted to emphasize the brands of Aalto-university and Gado in the robot since it`s taken to different venues and as such works as an "advertisement" for these instances. As it was in the plan to realize the design in tight schedule I put lot of attention to feasibility. The prototype can be easily done utilizing Fablab`s machines (laser cutter, 3D-printer) or the other workshops in the Aalto-University.

The casing of the robot can be 3D-printed. In the casing there`s some space for to attach sound isolation fabric (for example 2mm thick). Also there is some extra space inside of the casing for the cables to move freely. The idea behind the casing is that I wanted to connect visually the "leg" and the "body" of the robot. I also wanted the robot look good when it`s moving and in different positions. The parts of the casing are attached to each other with screws.

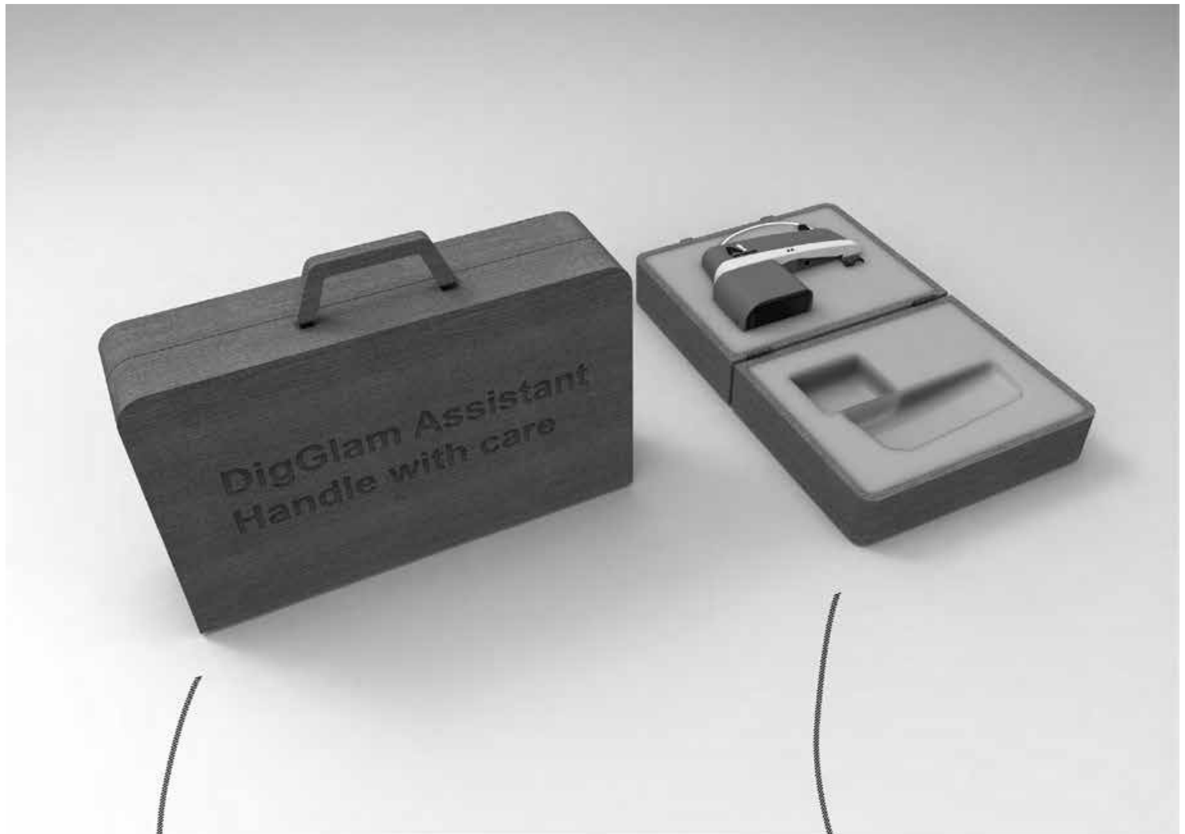
The deployment platform is made from plywood/ fibreboard by laser cutting layers and glueing them together. It has been measured so that it`s possible layer thickness could be 3mm, 6mm or 12mm. The deployment platform is foldable and there is fixed places for input tray, output tray and scanner. When folded the platform is like a suitcase. There`s a removable cover in the deployment platform so the cables and adapters can be hidden under it. The heights of the input tray and the scanner are possible to adjust by adding/ taking off layers. The camera stand is foldable, so it can be removed and easily packed for transportation. As the scanner`s place is on the same place as the hinges, it should be moved to other place underneath the cover for transportation. The robot should be removed from the deployment platform for its own suitcase for transportation since it`s not very shock-resistant.



GALLEN-KALLELA MUSEUM
(SOURCE: DIGGLAM PROJECT NOTES 2013-14)



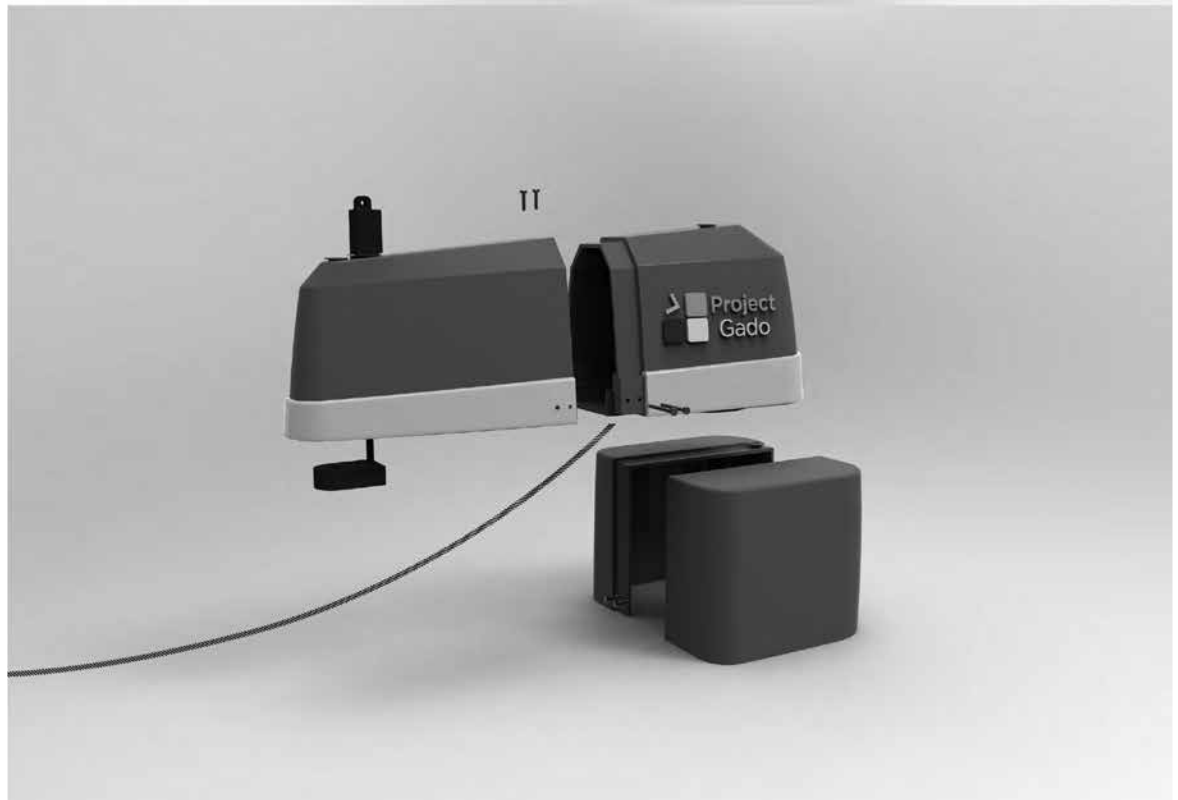
GALLEN-KALLELA MUSEUM
(SOURCE: DIGGLAM PROJECT NOTES 2013-14)



Deployment platform as folded

Cushioned suitcase for robot

Parts of the casing are attached to each other with screws. Casing is attached to the "arm" by hooks and screws



KEY TERMS, BIBLIOGRAPHY AND ILLUSTRATIONS

KEY TERMS

AMI. An abbreviation for advanced metering infrastructure. AMI are infrastructural systems that measure, collect, and analyze energy usage, and communicate with metering devices such as electricity meters, gas meters, heat meters, and water meters, either on request or on a schedule. These systems include hardware, software, communications, consumer energy displays and controllers, customer associated systems and supplier business systems.

API. An abbreviation for application programming interface. An application program interface (API) is a set of routines, protocols, and tools for building software applications. The API specifies how software components should interact and APIs are used when programming graphical user interface (GUI) components (see GUI). A good API makes it easier to develop a program by providing all the building blocks.

AWS. An abbreviation for Amazon Web Service, a cloud service provider. It provides cloud computing services that include computation, networking, content delivery, storage, database management, application services, analytics and others.

BENCHMARKING. It is the method of comparing processes and performance of a business or organization with industry standards and best practices.

BIM. An acronym for building information modeling. It is a digital three-dimensional repository of information of a building. The BIM process is able to construct a dynamic database model of a museum building that can be adjusted parametrically, edited across various scales, across several layouts with the editing of any one parametric object.

CCD. A charge-coupled device allows the movement of electric charge from within one device to where it can be converted into a digital value.

CARBON DIOXIDE (CO_2): A colorless, odorless, non-poisonous gas that is a normal part of Earth's atmosphere. Carbon dioxide is a product of fossil-fuel combustion as well as other processes. It is considered a greenhouse gas as it traps heat (infrared energy) radiated by the Earth into the atmosphere and thereby contributes to the potential for global warming.

CLIMATE CHANGE: A term used to refer to all forms of climatic inconsistency, but especially to significant change from one prevailing climatic condition to another. In some cases, "climate change" has been used synonymously with the term "global warming"; scientists, however, tend to use the term in a wider sense inclusive of natural changes in climate, including climatic cooling.

CLOUD COLLECTIONS. An industry term for the digital collections of a museum or any other cultural institution that are placed in remote computer servers hosted by a Cloud service provider. See also AWS.

CNC. An abbreviation for computer numerical control, by which machines and machine tools can be controlled and operated by programs and commands via a computer.

DAM. An acronym for digital asset management. It is a body of management tasks and decisions that guide the ingestion, annotation, cataloguing, storage, retrieval and distribution of digital assets.

DASHBOARDING. In management information systems, a dashboard is "an easy to read, often single page, real-time user interface, showing a graphical presentation of the current status (snapshot) and historical trends of an organization's key performance indicators to enable instantaneous and informed decisions to be made at a glance. Dashboarding is the act of constructing such graphical interfaces to provide a unified view.

ELECTRIC POWER GRID: A system of synchronized power providers and consumers connected by transmission and distribution lines and operated by one or more control centers.

ELECTRIC UTILITY: Any entity that generates, transmits, or distributes electricity and recovers the cost of its generation, transmission or distribution assets and operations, either directly or indirectly, through cost-based rates set by a separate regulatory authority (e.g., State Public Service Commission), or is owned by a governmental unit or the consumers that the entity serves.

ENERGY SERVICE PROVIDER: An energy entity that provides service to a retail or end-use customer.

ENTERPRISE SOFTWARE. A computer software that is typically aimed at the needs of organizations rather than individual users. These are usually business-oriented tools such as online shopping, billing systems, security etc. They are also development tools for building customized applications for any organization. Enterprise tools often interface with other enterprise software and are generally known for performance, scalability and robustness.

FAIR USE. This is a legal doctrine that promotes freedom of expression by permitting the unlicensed use of copyright-protected works in certain circumstances.

GITHUB. An online repository of computer code-sharing communities.

GNU. A recursive acronym for a free operating system (that is UNIX-like, contains no UNIX code) licensed under GPL.

GUI. An abbreviation for graphical user interface. It is a type of interface that allows users to interact with computers and electronic devices through graphical icons and other visual elements.

HVAC. An abbreviation for heating, ventilation and air-conditioning. It is a collection of mechanical and electrical technologies that deliver appropriate indoor air quality and thermal comfort.

INTERVAL METER. A smart electric meter that measures and records electrical use each hour and transmits the data back to the power company.

JSON. An acronym for JavaScript Object Notation is an open data-interchange format for storing and exchanging data. It uses human readable text to transmit data objects and is based on a subset of the JavaScript Programming Language.

LINEAR ACTUATOR. It is a type of motor that controls or moves a mechanism of a system along a straight line. They are extensively used in machine tools, and computer peripherals such as disk drives and printers.

LINUX. An open source computer operating system.

LUX. It is an acronym and SI unit of illuminance and luminous emittance, measuring luminous flux per unit area.

MICROCONTROLLER. It is small computer, a self-contained system that has a single integrated circuit containing a processor, memory and input / output terminals. They are usually embedded in the devices that utilize them.

MYSQL. An acronym for structured query language. It is a popular choice of database for use in web applications. MySQL is used by most social networks and large web companies such as Facebook, Twitter, Google, etc. MySQL can also be run on cloud computing platforms such as Amazon EC2. Many programming languages with language-specific APIs include libraries for accessing MySQL databases.

NFC. An abbreviation for near field communications, it is a set of communication protocols that enable two electronic devices, one of which is usually a portable device such as a smartphone, to establish communication by bringing them within 4 cm (2 in) of each other. This wireless technology uses short range radio waves and magnetic field induction. Thus, devices can communicate with each other using NFC technology when they touch each other or brought very close to each other.

OCR. An abbreviation for optical character recognition. It is the electronic or digital conversion of handwritten or typed images into machine-readable text.

PHP. An abbreviation for hypertext preprocessor. It is an open source server-side scripting and general purpose programming language. It can be easily embedded into HTML code, or used in combination with various web template systems, content management systems and frameworks. PHP can be used to create dynamic web page content. Facebook, the social network uses PHP for its user-facing interfaces.

REST. An acronym for representational state transfer. It is an architecture style for designing networked applications. The idea is that, rather than using complex mechanisms such as CORBA, RPC or SOAP to connect between machines, simple HTTP is used to make calls between machines. The World Wide Web itself, based on HTTP, can be viewed as a REST-based architecture. RESTful applications use HTTP requests to post data (create and/or update), read data (e.g., make queries), and delete data. See more: http://rest.elkstein.org

RH. An abbreviation for relative humidity. It is the ratio of the partial pressure of water vapor to the equilibrium vapor pressure of water at the same temperature. Indoor climate control depends on the adjustments of temperature and relative humidity.

STL. An abbreviation for stereolithography. It is a file format native to the stereolithography computer aided design (CAD) software created by 3D Systems.

TUI. An abbreviation for tangible user interface. It is a type of physical interface that one uses to negotiate and interact with digital information.

TWAIN. A backronym that defines a standard software protocol and API (application programming interface) for communication between software applications and image acquisition devices.

UNIX. A family of operating systems. It's features are modular design, unified file system, portability and the use of shell scripting and command language. The operating system is written in C programming language.

USB. An abbreviation for universal serial bus. It is an industry standard that defines the cables, connectors and communication protocols used in a bus (a communication system hardware that transfers data between computers) for connections, communication and power supply between devices.

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ILLUSTRATIONS

FIGURES

TABLES