BUILDING THE IMMATERIAL

Building the Immaterial

Data Centers, The Quarries of Tomorrow

Enoncé Théorique
2019 MA. Arch.
Ecole Polytechnique Fédérale de Lausanne

Matthieu Brasebin

Prof. Harry Gugger
Second Prof. Dieter Dietz
Maître EPFL. Augustin Clément
Lab. LABA

Ce document est mis à disposition selon les termes de la Licence Creative Commons Attribution (CC BY https://creativecommons.org/licenses/by/4.0)

Vous pouvez utiliser, distribuer et reproduire le matériel par tous moyens et sous tous formats, à condition de créditer l'auteur de l'œuvre.

Les contenus provenant de sources externes ne sont pas soumis à la licence CC BY et leur utilisation nécessite l'autorisation de leurs auteurs.

Abstract

Over thousands of years, we have been accumulating knowledge in order to manage our environment. We have been extracting resources to provide shelters. We have been digging holes all over the surface of the earth, revealing a hidden geography of local depletions. Those places, where geological resources have been exhausted, remain now unused and unconsidered. Quarries as we call them.

On the other hand, for less than a few decades, we have been operating a massive shift of materiality. We have been de-materializing our knowledge thanks to a global infrastructure of computer farms. We have been designing buildings to host servers that process information constantly, making Data the most abundant resource of our time. Those Data Centers are in fact the quarries of tomorrow.

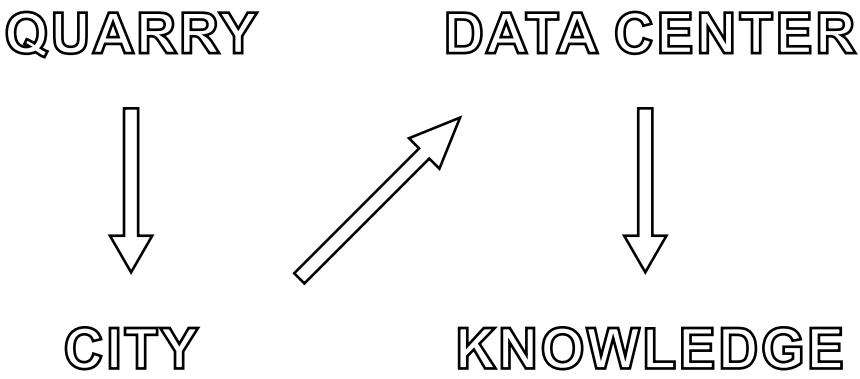

QUARRY
DATA CENTER
CITY
KNOWLEDGE

TABLE OF CONTENT

08
FROM MATERIAL TO VIRTUAL

10 Process
12 Globalization
14 Virtualization
16 Infrastructures

18
CRITICAL INFRASTRUCTURES

20 Disused Quarries x Mega Data Centers
24 Remote Entities
32 Spatial Configurations
40 Hyper-objects
48 Distributions

58
RETHINKING OBSOLESCENCE

60 Life Cycle
62 Environmental Scars
68 System Overlap
76 The Quarries of Tomorrow

FROM MATERIAL TO VIRTUAL

10 PROCESS
From minerals to materials

12 GLOBALIZATION
From local resources to global infrastructures

14 VIRTUALIZATION
From natural to virtual environment

16 INFRASTRUCTURES
From quarries to data centers

Process

Resource management determine our territorial organization. From the exploitation towards the distribution, infrastructures cross the earth's landscape, transferring large amounts of materials, water and energy to our urbanized environments. They define a spatial interface between the resource and its product.[1]

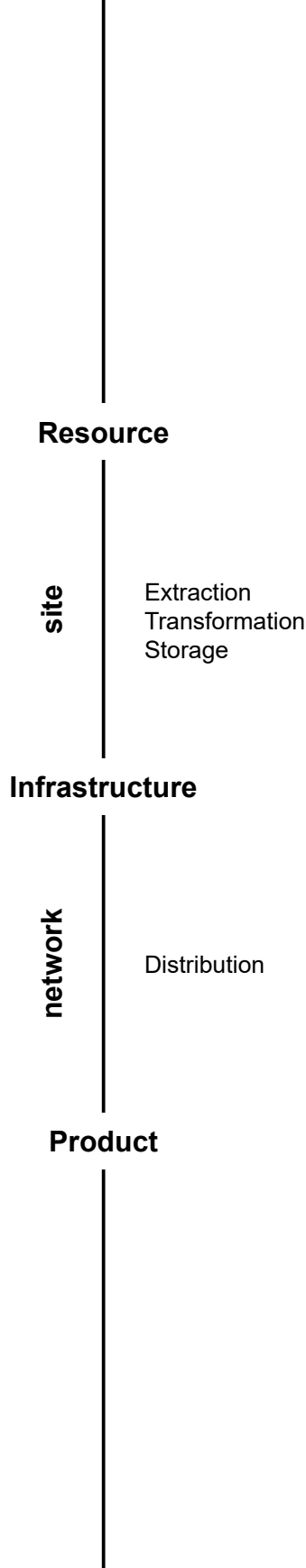
This configuration is divided into two clear systems: discrete places, in which resources are extracted, transformed and stored, and distribution lines such as roads, cables, and pipes.[2] Together, they constitute a wide network of nodes and paths[3] regulated by logistics.[4] Information controls every aspect of this process from the very raw minerals to the highly advanced materials.

"The infrastructure that made possible the last half millennium of urbanization was concieved as a one-way system providing a predictable flow of resources in lieu of nature's volatile processes."
1. Pierre Bélanger, *Landscape as Infrastructure: a Base Primer*, 2017, Abingdon, Oxon: Routledge, p. 12

"The energy concealed in nature is unlocked, what is unlocked is transformed, what is transformed is stored up, what is stored up is, in turn, distributed, and what is distributed is switched about ever anew."
2. Martin Heidegger, *The Question Concerning Technology and Other Essays*, 1977, New York: Garland Publishing, p. 16

"The paradigmatic (or "significant") opposition between exchange and use, between global networks and the determinate locations of production and consumption, is transformed here into a dialectical contradiction, and in the process it becomes spatial."
3. Henri Lefebvre, *The Production of Space*, 1991, Oxford: Blackwell, p. 341

"Through the combination of the abstract and the concrete, through the conflation of time and distance, and through the deployment of elements both networked and discrete, logistics requires the creation of objects, systems, and environments that both mirror and reproduce these conditions."
4. Jesse LeCavalier, *The Rule of Logistics: Walmart and the Architecture of Fulfillment,* 2016, Minneapolis: University of Minnesota Press p. 31


Resource
site
Extraction
Transformation
Storage
Infrastructure
network
Distribution
Product

Globalization

If geologic resources will always remain local because of their spatial distribution, infrastructure has grown from the intimate scale of early societies to reach a global configuration, supporting intense circulation and exchanges[5] at the contemporary age of digital communications. For instance, minerals besides their growing extraction in isolated mines and quarries,[6] are intensely exported worldwide as well as fossil fuels.

This major shift, nurtured by our increasing understanding of nature, from the cognitive revolution towards the emergence of technological sciences, depicts how knowledge has led to the extraction of rare-earth minerals that invade our computers,[7] as well as the discovery of always more powerful energies, essential for the invention of ever new technologies.

As a result, logistics have taken over the flow of traded goods. Information archiving and Data sharing became the most global traffic, due to their instant and worldwide accessibility. Their accumulation is exponential, so is their value that has overpassed the currency of material goods such as oil. In fact, Data has turned to be the most valuable resource of our time.[8]

"The arrival of industrialization, ushering in the Anthropocene, is marked by the human ability to move vast quantities of geologic material."
5. Jussy Parikka, *A Geology of Media*, 2015, London: Electronics Mediations, p. 52

"Quarrying was not on a large scale until nineteenth centuries, when there was an increasing demand from large towns and industrial districts."
6. Peter H. Stanier, *Quarries and Quarrying*, 1985, Aylesbury : Shire Publications, p.3

"We have shifted from being a society that until the mid-twentieth century was based on a very restricted list of materials ("wood, brick, iron, copper, gold, silver, and a few plastics") to the fact that even a computer chip is composed of "60 different elements."
7. Jussy Parikka, *A Geology of Media*, 2015, London: Electronics Mediations, p. 35

"In the process, Dataism inverts traditional pyramid of learning. Hitherto, data was seen as only the first step in a long chain of intellectual activity. Humans were supposed to distill data into information, information into knowledge, knowledge into wisdom."
8. Yuval Noah Harari, *Homo Deus: A Brief History of Tomorrow*, 2015, Vintage, p. 428

Local Resources
Minerals
Fossils
Informations
Sedentarization
stone
Earth
wood
Hearth
cognition
Hearth
Industrialization
iron ore
copper
Quarry
coal
gaz
oil
Mine
Well
philosophy
science
Library
Digital
Communications
rare-earth
minerals
Mine
nuclear
renewable
Power Plant
technology
media
Archive
Data Center
Quarry
Mine
Data Center
Global Infrastructure

Virtualization

Infrastructures reveal our imprint on the natural environment. They constitute an overlaid system that operate transitions between the geological and the artificial.[9]

Extraction processes are therefore at the core of such a crossover. Indeed, the very fact of mining, of removing natural resources from their ground, states a change of dimension. Extracted minerals, once processed are in fact raw products that support our built environment.

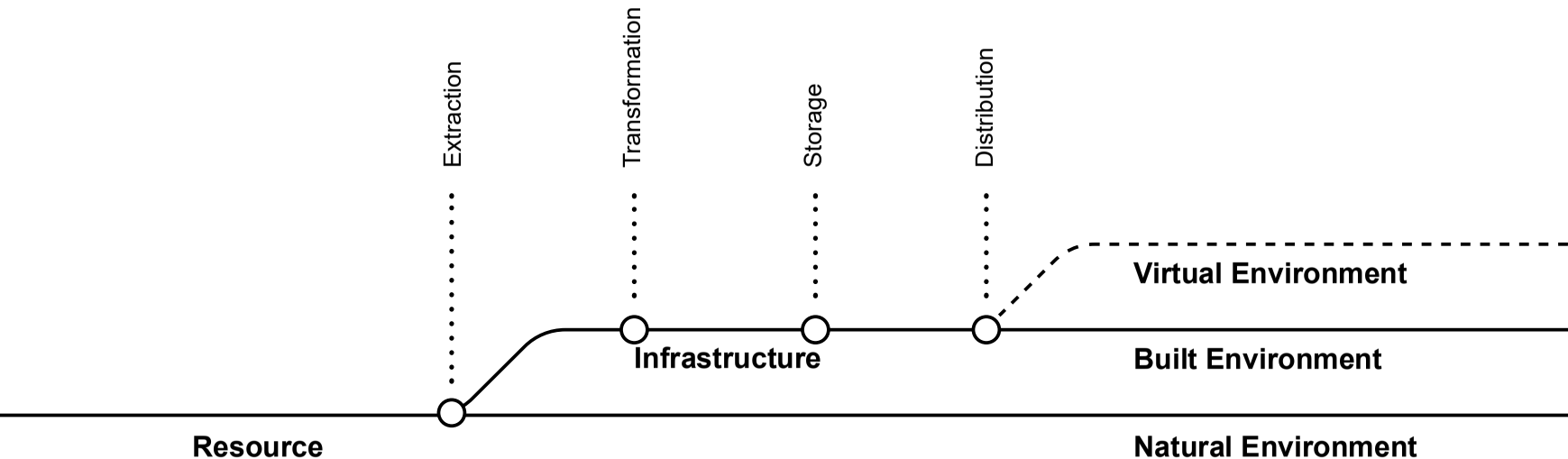
Transformation and storage complete this mechanism till the distribution of the final outputs that iterate another degree of layering: a split between the material and the virtual.

This virtual environment in which we share knowledge and trade information in order to optimize logistics have become an entire landscape by its own.[10] It both informs and complete the built environment, as well as it belongs to it by its physical infrastructure,[11] data centers.

"The relations to the earth are also part of the social relations of labor and exploitation that characterized emerging industrial capitalism of the nineteenth century as much as they characterize contemporary digital capitalism of the twenty-first century from mining minerals, geopolitics of the hunt for energy, and material resources to the factories of production of computational equipment."
9. Jussy Parikka, *A Geology of Media*, 2015, London: Electronics Mediations, p. viii

"Thus imagining logistically requires the understanding of a given landscape as simultaneously terrain and territory, physical and abstract, material and informational."
10. Jesse LeCavalier, *The Rule of Logistics: Walmart and the Architecture of Fulfillment,* 2016, Minneapolis: University of Minnesota Press p. 42

"Digital technology, which was once the figure instead of the ground, slowly becomes the ground of governance, communication, and scientific research methods."
11. Yuk Hui and Andreas Broeckmann, *30 Years after Les Immatériaux: Art, Science, and Theory*, 2015, Menson Press, p. 16


Extraction
Transformation
Storage
Distribution
Virtual Environment
Infrastructure
Built Environment
Resource
Natural Environment

Infrastructures

Quarries and data centers can be therefore considered at the origin of respectively our built and virtual environment. They both define turning points between two *milieus*: Quarries are extraction sites in which we process natural resources, as well as data centers are physical entities that store and exchange dematerialized information.

But data centers as well derive from the geological. They are filled in with servers, made of metals obtained by the transformation of rare-earth minerals.[12]

Because of the drastic demand for data storage,[13] data centers are willing to expand always more. Their storage capacity is expected to quadruple within 5 years.[14]

On the other hand, quarries due to the exhaustion of their resources are today for the most abandoned.[15]

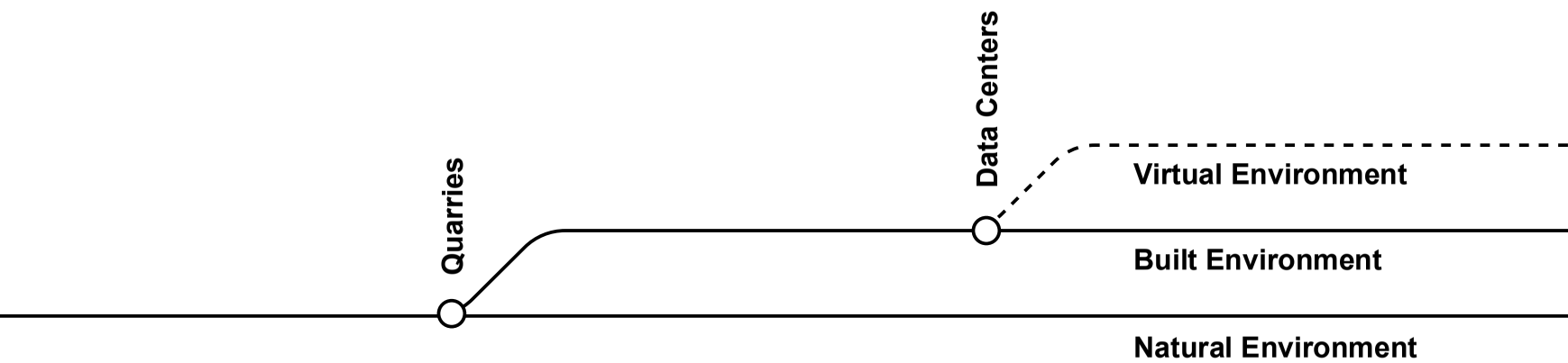
These two opposites tendencies make of them critical infrastructures, whose immense imprint, remain unknown to many of us.

"Media history conflates with earth history; the geological materials of metals and chemicals gets deterritorialized from their strata and reterritorialized in machines that define our technical media culture."
12. Jussy Parikka, *A Geology of Media*, 2015, London: Electronics Mediations, p. 35

"The volume of all data stored will almost triple by 2021 from 1.8 ZB to 7.2 ZB. Most data is stored on client devices (84%), but more moves to data center over time."
13. *Cisco Global Cloud Index: Forecast and Methodology, 2016–2021*, p. 23

"We estimate that total data center storage capacity will grow nearly 4-fold from 2016 to 2021, growing from 663 EB in 2016 to 2.6 ZB by 2021."
14. *Cisco Global Cloud Index: Forecast and Methodology, 2016–2021*, p. 21

"2'000 entries pertaining to active mineral workings and a much larger number for inactive and former workings, totaling 193'470 entries."
15. *Directory of Mines and Quarries*, British Geological Survey, 2014


Quarries
Data Centers
Virtual Environment
Built Environment
Natural Environment

CRITICAL INFRASTRUCTURES

20 DISUSED QUARRIES X MEGA DATA CENTERS

Canadian Extraction Empire vs USA Mega Data Centers Leadership

24 REMOTE ENTITIES

Natural Distribution vs Infrastructural Support

32 SPATIAL CONFIGURATIONS

Isolated Quarries vs Data Center Campus

40 HYPER-OBJECTS

Subtractive Design vs Additive Design

48 DISTRIBUTIONS

Mobile Transportation vs Static Communication Cables

DISUSED QUARRIES

North America leads the infrastructural world both in terms of minerals extraction and data possession. Indeed, the Canadian government operates nearly half of the 20 000 active mining sites in the world.[1] 4/5 of the workers are employed by large scale and medium size enterprises,[2,3] over which, 2/3 are headquartered in Canada.[4] This foreground position states a notable geography of power over the worldwide spread of geologic resources.[5]

Quarries are usually located along river bends, in remote places, distant from urbanized areas,[6] where natural resources are found in abundance.[7] Their opening depends on legal regulation - Canadian laws being quite loose about them - and proximity to infrastructure such as roads, railways and electrical power supplies.[8] Most of them are dedicated to aggregates, primer material by far for construction and road coating.[9] Indeed, every American born will consume nearly as much aggregate than any other material and fossil fuel that support his daily life.[10]

If today, most of the quarries remain disused,[11] offering incredible landscapes shaped by mining machines, their territorial organization present specific patterns, similar to the ones that host and rule our technological and media-crazed world.[12]

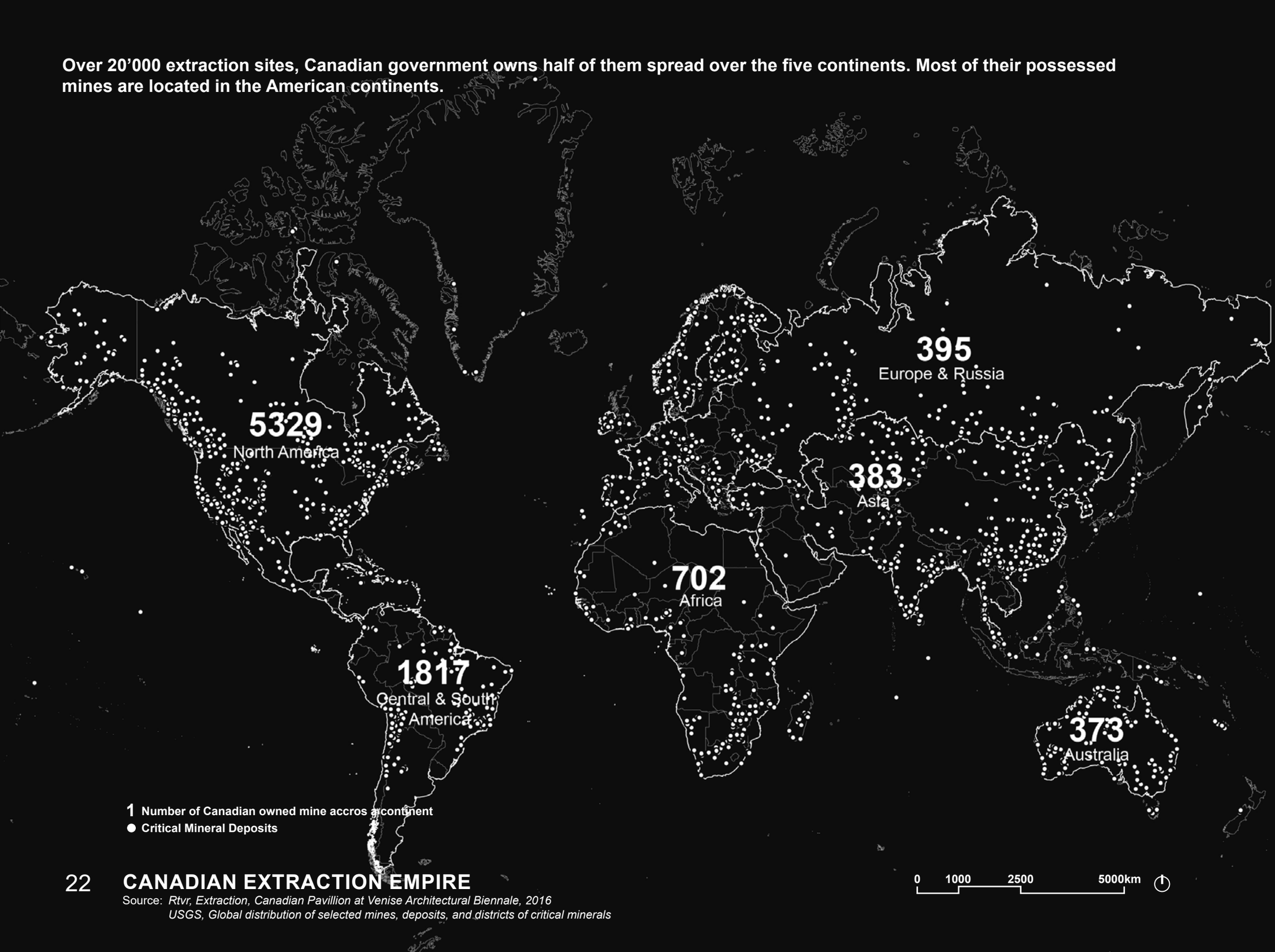
MEGA DATA CENTERS

Hyper-scale data centers or mega data centers represent less than 1% of all the facilities hosting servers in the USA.[13] However, at a worldwide scale, mega data centers will represent next year more than half of the servers installed, within no more than 628 facilities.[14] The USA own 38% of them, China sitting at a distant second place with only 10%.[15]

Each building compiles in average more than 100'000 servers on an area of at least 25'000m^2.[16] Many of them are owned by private providers that rent storage capacity to enterprises, multinational companies having their own facilities.[17] There are mostly dedicated to collocation, but as well for financial purposes, telecommunications, cloud services, and governmental logistics along many others.[18] For instance, the US government possess 12'000 data centers,[19] 40% of the servers being devoted to the defense department.[20]

Due to the high sensibility of the information they detain, data centers besides their strict security rules[21] and redundant design in case of blackout,[22] appears as blank boxes, trying to keep low profile has much as possible.[23] Even though they can be placed almost anywhere where electricity is available in very large amounts and connection to fiber optic is well provided,[24] many of them are located in remote places, in order to satisfy their privacy needs.

Over 20’000 extraction sites, Canadian government owns half of them spread over the five continents. Most of their possessed mines are located in the American continents.



CANADIAN EXTRACTION EMPIRE

Source: *Rtvr, Extraction, Canadian Pavillion at Venise Architectural Biennale, 2016*
USGS, Global distribution of selected mines, deposits, and districts of critical minerals

Data center's infrastructure deploys worldwide. Its interconnections are ensured by optical cables,[25] buried on the ground and running under oceans. They constitute the 'backbone' of the global digital ecosystem,[26] a network of currently 378 cables with a total length of nearly 1.2 million kilometers.[27] Putting one after another, they can wrap almost 30 times our planet.
Hyper-scale data centers are for the most located around big nodes, well connected to transcontinental fiber optics.

HYPERSCALE DATA CENTER GLOBAL NETWORK

Source: *Telegeography*
**Google, Amazon, Facebook, Apple*

Remote Entities

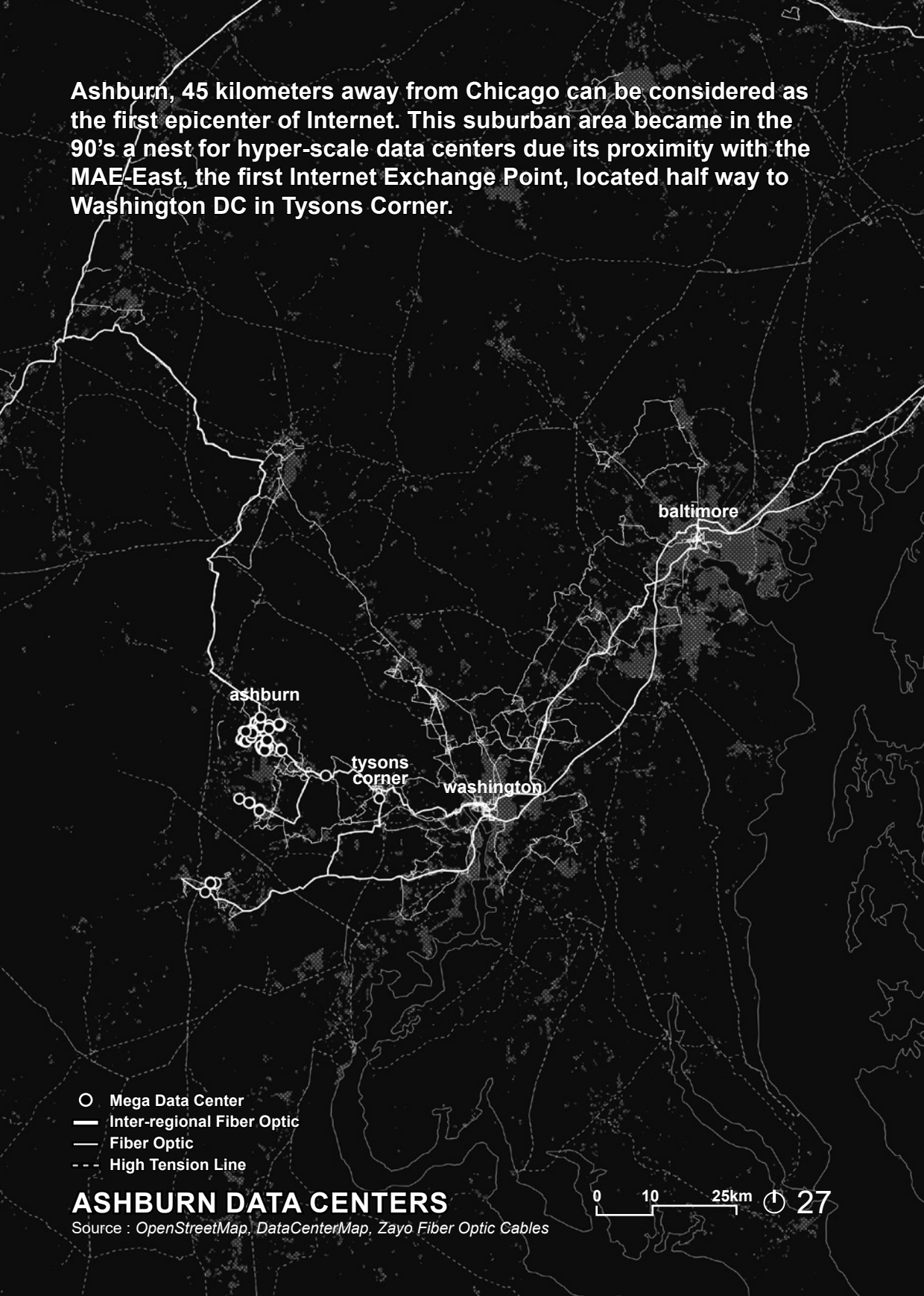
Often perceived as hinterland entities, quarries and data center are defined by similar territorial distributions, ones that follow electrical power lines, water streams and fiber optic cables.

As a typological study, three territories that represent both primordial nodes for digital communication networks and presence of important quarries have been taken. Those location choices were conducted, for the two first ones by their historical background, being the two first Internet Exchange Points, and for the last one by the presence of the two biggest aggregate quarries in the world. In this regard, Ashburn (Virginia), San José (California) and Chicago (Illinois) are exposed as major links that support both our construction and media industries.

26 **ASHBURN QUARRIES**

Source : *OpenStreetMap, USGS*

Ashburn, 45 kilometers away from Chicago can be considered as the first epicenter of Internet. This suburban area became in the 90's a nest for hyper-scale data centers due its proximity with the MAE-East, the first Internet Exchange Point, located half way to Washington DC in Tysons Corner.



ASHBURN DATA CENTERS

Source : *OpenStreetMap, DataCenterMap, Zayo Fiber Optic Cables*

28 **SILICON VALLEY QUARRIES**

Source : *OpenStreetMap, USGS*

San José, California, is in a sense, the little brother of Ashburn. It respects same principles of organization, its mega data centers being located nearby the MAE-West in Palo Alto, now called the 'PAIX', the Palo Alto Internet Exchange.

SILICON VALLEY DATA CENTERS

Source : *OpenStreetMap, DataCenterMap, Zayo Fiber Optic Cables*

30 **CHICAGO QUARRIES**

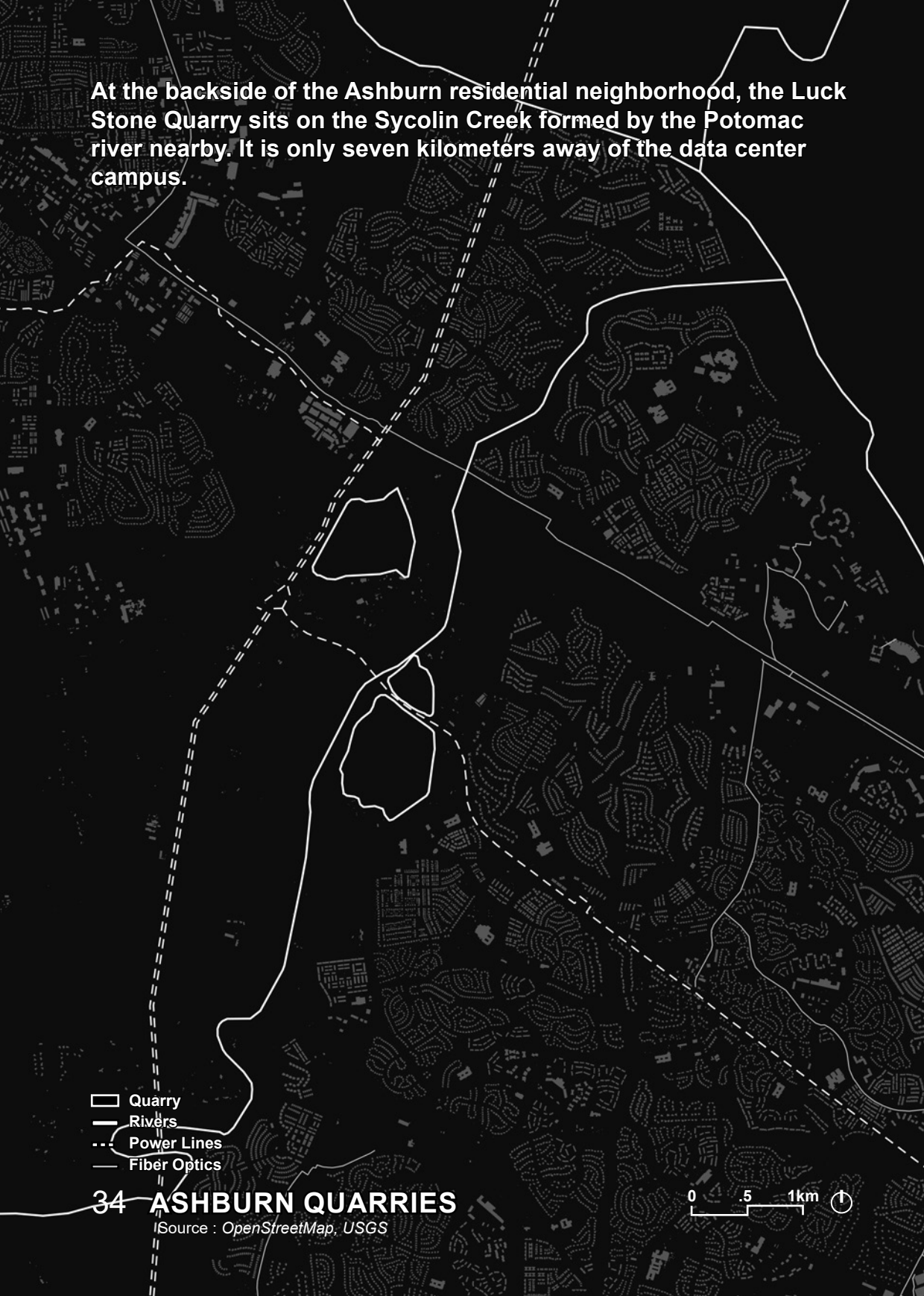
Source : *OpenStreetMap, USGS*

Either concentrated in the city center or in urban peripheries, most of Chicago's data centers are in fact concentrated next to the O'Hare International Airport.
o'hare international airport
chicago
Mega Data Center
Inter-regional Fiber Optic
Fiber Optic
High Tension Line
CHICAGO DATA CENTERS
Source : OpenStreetMap, DataCenterMap, Zayo Fiber Optic Cables
0
10
25km
31

Spatial Configurations

Far from densely urbanized areas, quarries appear as isolated landscapes. Even if they are located next to important roads or at the backside of a residential suburb, they remain unnoticed, if not invisible, often hidden by proximate vegetation at their boundaries. This situation of enclosure and detachment is however supported by the presence of electrical networks, indispensables to the service of processing engines.

When regrouped in suburban neighborhoods, data centers are organized alike campuses, taking advantage of the already present infrastructures. In that case, they are mostly located in industrial districts, close to important facilities such as airports and distribution depot, placed under the surveillance of military contractors.



34 **ASHBURN QUARRIES**

Source : *OpenStreetMap, USGS*

Ashburn mega data centers are particular for their agglomerated concentration. Among them, DuPont Fabros Technology owns the third biggest data center in the world, spread over seven facilities at the heart of the campus. Close to a military zone, the area is therefore settled under good surveillance.[28]
Data Center
Power Lines
Fiber Optics
ASHBURN DATA CENTERS
Source : OpenStreetMap, DataCenterMap, Zayo Fiber Optic Cables
0
.5
1km
35

36 **SILICON VALLEY QUARRIES**

Source : *OpenStreetMap, USGS*

Data Center
Power Lines
Fiber Optics

SILICON VALLEY DATA CENTERS

Source : *OpenStreetMap, DataCenterMap, Zayo Fiber Optic Cables*

0 .5 1km

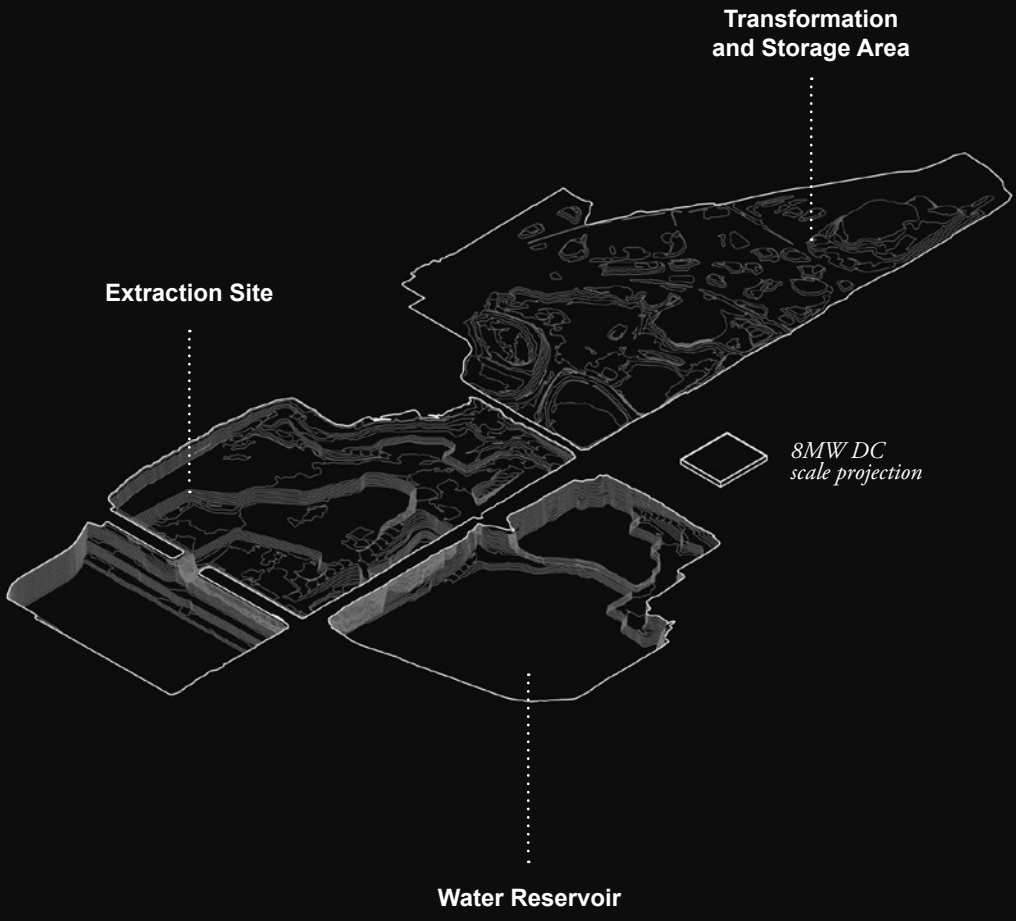
Similarly to San José, Chicago mega data centers take place aside of the city's main airport, surrounded by industries and depots.
Data Center
Power Lines
Fiber Optics
CHICAGO DATA CENTERS
Source : OpenStreetMap, DataCenterMap, Zayo Fiber Optic Cables
0
.5
1km
39

Hyper-objects

Quarries and data centers are hard to measure because of their massive scale. Their design rules make of them opposite subjects in the sense that the first one is dedicated to the subtraction of matter whereas the second one is defined by an addition of prefabricated elements.

Quarries result *of* the process of mining machines, whereas data centers are designed *for* the process of computing machines. In both case, human presence is there incidental,[29] quite a contradictory situation for two infrastructures at the basis of both our material and virtual human made environments.

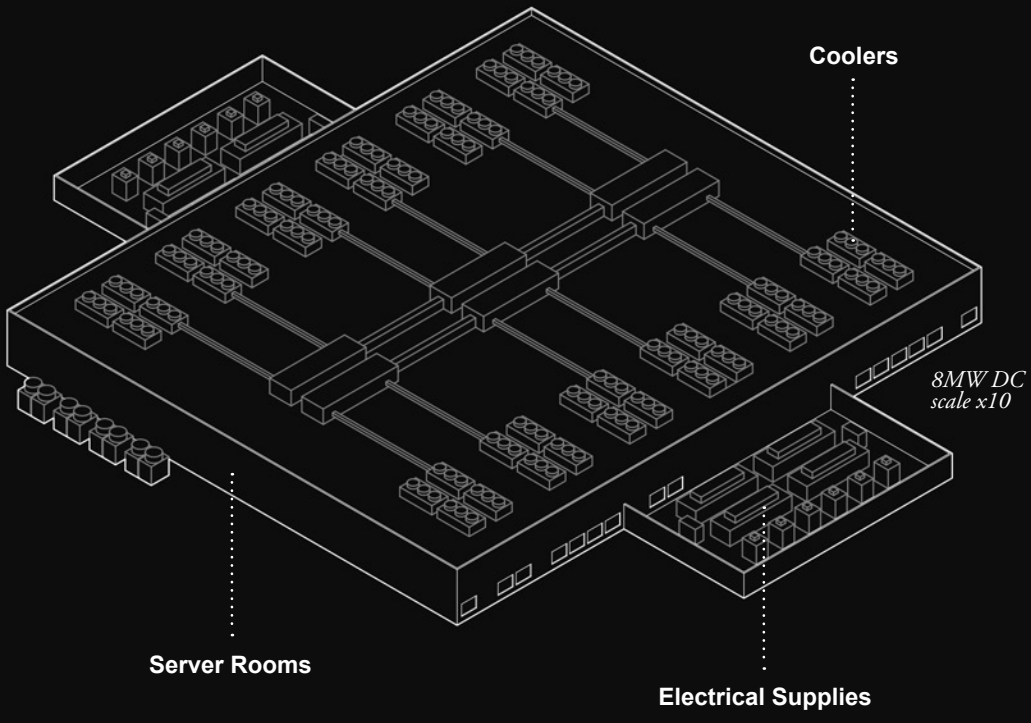
The design of a quarry results on the extraction techniques employed in its processing. It as well depends on the geology and topography of sedimentary rocks.[30] Its layout is split into two main parts: excavation sites where minerals are extracted and transformation - storage areas where minerals are crushed and then laid down within several piles.



42 **THORNTON QUARRY AXO**

Source : *OpenStreetMap, LIDAR Topography*

The shape of a data center has no specific guiding rules except the one providing secure and energetically redundant environmental controlled rooms for servers. Because 80% of a data center budget goes on IT and electrical equipment - only 1% on the land - the cost for the structure is so minimal that the shape of the building gets almost no constraints.[31] The building can either be completely flat, or a tower of twenty stories, this does not matter. Only the interior layout is decisive.



8MW DATA CENTER AXO

Source : *8MW DC01 - C+K Architects*

A quarry scale can only be understood through the one of its products. It has to be measured within the amount of material they produce. As they look alike natural landscapes, there is no standard elements inside them - except processing machines - to be compared with.

69 Million T

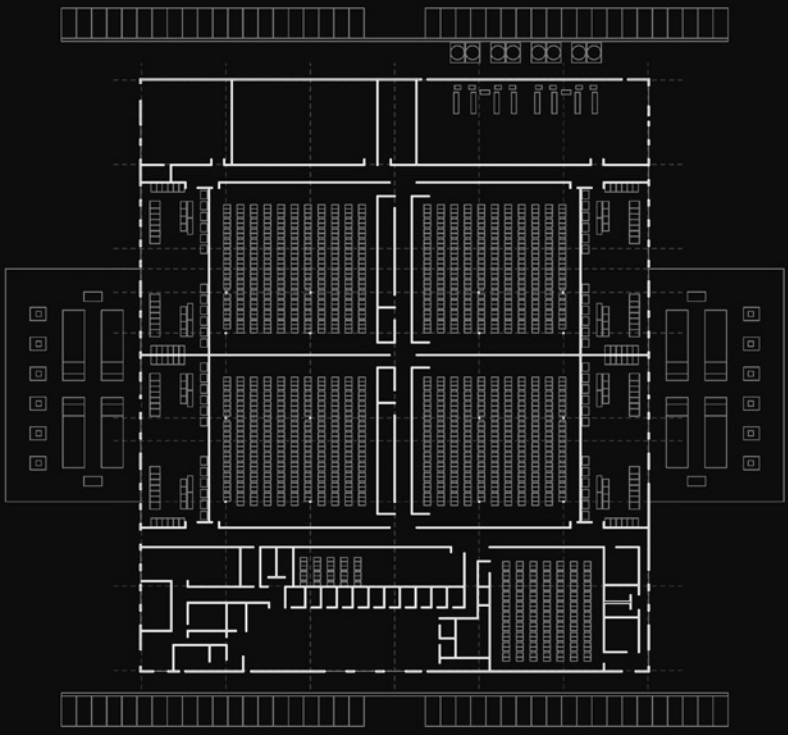
Equivalence of 152 Biilion lb of dolomite limestone removed during the full operation.[32]

44 **THORNTON QUARRY PLAN**

Source : *OpenStreetMap, LIDAR Topography*

0 250 500m

Contrary to the quarry, the scale of a data center cannot be understood by its product, data, but by the physical entities that produce it, servers. Server racks therefore become the unit of measure of such an infrastructure.[33]



1’625 T

Average weight of the 1298 servers hosted in the 8MW data center by C+K Architects.[34]

8MW DATA CENTER PLAN

Source : *8MW DC01 - C+K Architects*

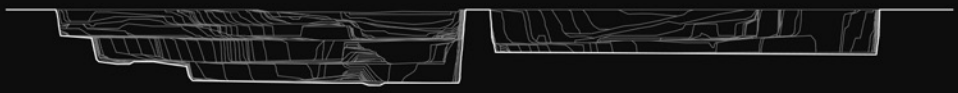
0 10 20m

Mineral extraction needs impressive amount of energy. Within the process, 30 to 40% of the power is consumed by explosives.[35] Electrical is as well needed in large quantities: half of it is dedicated to crushers and screens that sort extracted minerals by size.[36] Because aggregate minerals are heavy, their transportation far exceeds the energy involved in the extraction and the transformation.[37]

1300 GWh

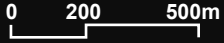
Equivalence of the 4 725 655 GJ of energy consumed by Australia's Super Pit in 2014[38].

No data was available for the Thornton quarry but the amount of energy used to extract minerals should be close to the one of the Australia's Super Pit, the size of both quarries being quite similar. Even though the type of material dug in the Australian and the American quarry is different, it doesn't affect much the amount of energy used to process those extractions.



46 **THORNTON QUARRY SECTION**

Source : *OpenStreetMap, LIDAR Topography*



Because of the large number of servers which need to be kept cool, data centers consume a lot of electricity. Almost 200 times the consumption of a conventional commercial building.[39] 45% is used to power ICT equipment (servers mainly, network routers...) the other part being dedicated mostly to power distribution systems, redundant power supplies and chillers, lighting counting for almost nothing.[40]

13 GWh

Amount of Energy consumed by one Equinix Data Center in average.

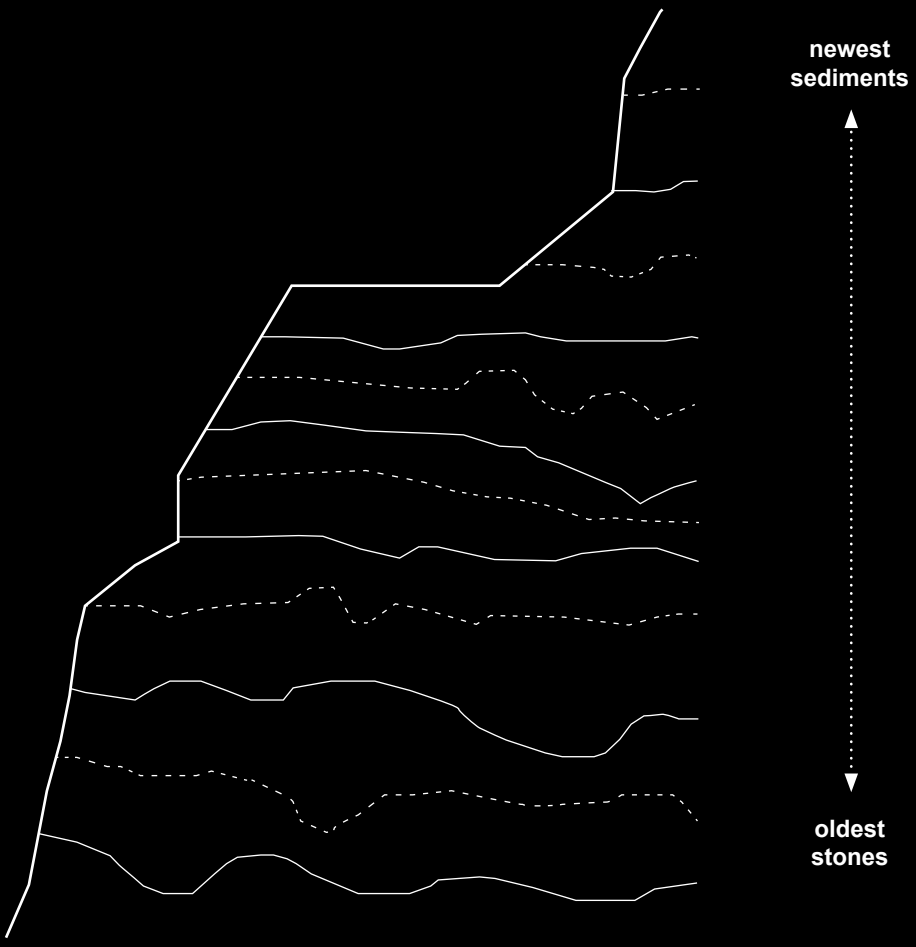
In 2014 the company consumed more than 2200 GWh within its almost 170 DC.[41,42]

8MW DATA CENTER SECTION

Source : *8MW DC01 - C+K Architects*

0 10 20m

Quarries reveals earth records by digging onto sediment's stratification history. They are poetic places, telling about geological memories. In them, *depth becomes time*.[43]



48 **THORNTON GEOLOGIC SECTION** 0 20 40cm

Data centers record our memory. They are the biggest archives of our time. Their storage capacity is only limited by a certain number of servers, drastically increasing. Similarly to sediment formations, the oldest servers are usually located at the bottom of a server rack, where first cables have been installed.[44]

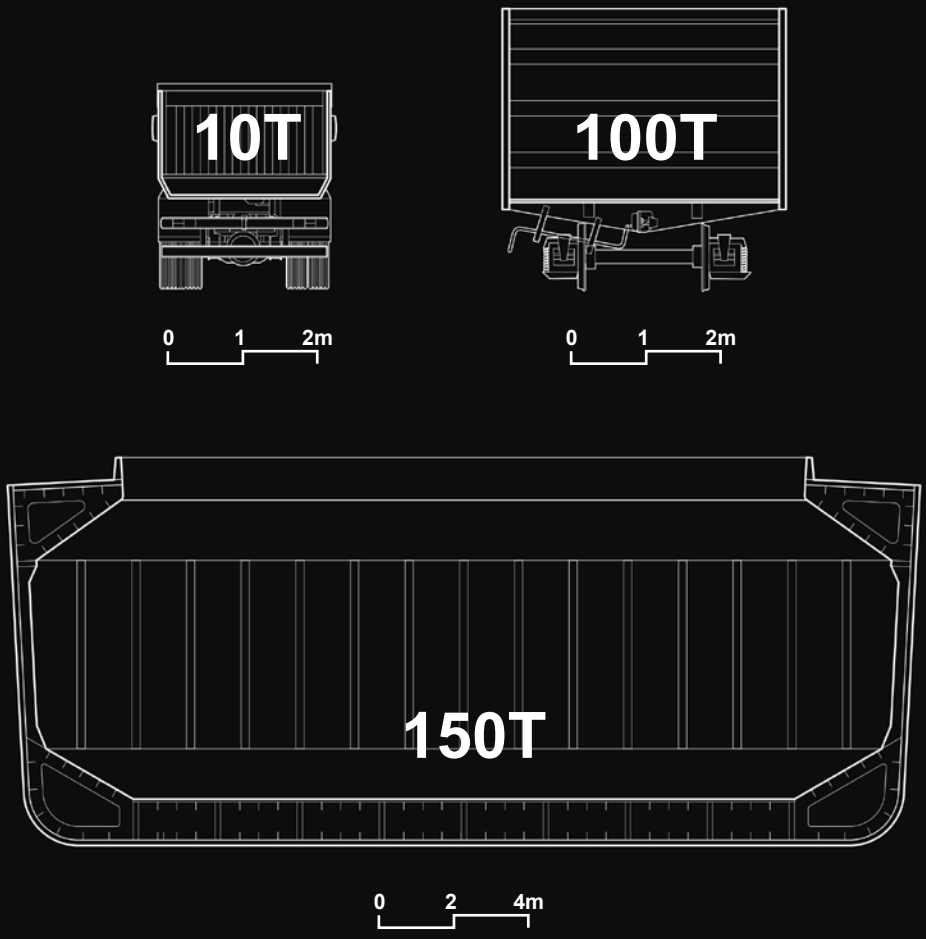
8MW DATA CENTER RACK

0 20 40cm

Distributions

Finally, the material products of a quarry and the immaterial one of a data center have to be distributed through specific networks in order to be exploited. Due to their heaviness or on the contrary their immateriality, movement is taken by either mobile infrastructures in the case of mineral or static ones in the case of data which is carried by light through space.

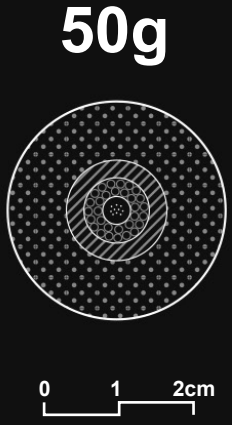
Mineral transportation from the extraction to the processing sites, happens mainly by road. Another important part is conducted by train if the railway connection between the quarry and the factory is easily accessible.[45] Finally, the last part concerns maritime flows, thanks to which, large amounts can be transfered in a single travel.



52 **AGGREGATES TRANSPORT SECTIONS**

Source : *Aggregate Transportation - Quarry Management / A Guide to Aggregate and its Supply and delivery, 2016, Waste Disposal Hub*

Most of our data travels through optical cables. 99% of it.[46] The other part runs thanks to old communication cables (telephone lines) or satellites. Fiber optic is by the far the cheapest and fastest way to transfer data, very securely. Those cables are incredibly thin as optical fiber is able to transport very large amounts of information through light. Speaking of data, their total weight reaches no more than 50 grams, light being constituted of nano particles of which the weight is almost null.



SUBMARINE CABLE SECTION
Source : *Vodaphone Group 2018*

Notes

"More than half of the mining operations in the world are Canadian-owned, operated, equipped, or engineered."
1. Pierre Bélanger, *Extraction Empire: 2017 - 1217,* 2018, Cambridge: MIT Press, p. 6

"64% of employed is state within large scale enterprises, 14% by medium sized, 14% by small and the remaining 8% by micro ones."
2. Eurosat, *Sectoral Analysis of employement by entreprise size class, Mining and Quarrying, (NACE Section B), EU-28,* 2016

"Global mining and quarrying is characterized by a small number of international enterprise groups that operate across continents in conjunction with smaller companies."
3. Anne Whiston Spirn, *No Longer Just a Hole in the Ground,* MIT*,* 2013, p. 5

"2/3 of the world's mining companies are headquartered in Canada, thanks to low royalty rates set by the Crown and favorable investment environments of the Toronto Stock Exchange."
4. Pierre Bélanger, *Extraction Empire: 2017 - 1217,* 2018, Cambridge: MIT Press, p. 7

"Territories of extraction cover more than 80% of the planet, extending across lands on which the majority of the world's 7.5 billion people live."
5. Pierre Bélanger, *Extraction Empire: 2017 - 1217,* 2018, Cambridge: MIT Press, p. 5

"Often perceived as remote, and deftly marginalized as hinterlands, the sites and systems of resource mining not only expose the scales and states of industrial extraction, but they also redraw the boundaries of urban economies and extents of patterns of consumption, well beyond the gray zones and footprints of cities."
6. Pierre Bélanger, *Extraction Empire: 2017 - 1217,* 2018, Cambridge: MIT Press, p. 23

"The availability of appropriate rock material is determined by the geological structure, while the accessibility of the materials is often limited by planning constraints."
7. Ian Hill, *A progress report on the Energy-Efficient Quarry project,* 2012, p. 130

"The development of a mine is affected by various natural conditions including geographical location as well as various social and political conditions including legal regulation, tax, and such public utilities as railway, road, water and electric power supplies, etc. at the area and country where the mine is constructed and operated."
8. Kiyoshi Horikawa & Qizhong Guo, *Civil Engineering - Volume II,* 2009,Oxford: Eolss Publishers, p. 136

"The classification of aggregates, bulk construction materials whose extraction dominates the mass of annually mined minerals."
9. Vaclav Smil, *Making the Modern World: Materials and Dematerialization,* 2014, New Jersey: Wiley publisher, p. 53

"Every American born will need 1.36 million pounds of stone, sand & gravel over the 3.19 million pounds of minerals, metals and fuels, they will consume in their lifetime."
10. Mineral Education Coalition, *The Baby,* 2019

"Only a few small quarries remain in operation."
11. Peter H. Stanier, *Quarries and Quarrying,* 1985, London: Shire Publications, p. 8

"A new geography has emerged, one that knits together the infrastructure of networks, the mesh of fiber-optic cables, data centers, electromagnetic waves, and the extraction of resources."
12. Ippolito Pestellini Laparelli, *Data Matter*, in Flash Art n° 326, Jun-Aug 2019, p. 55

Table 1.1 Data center type, server volume, and typical size: estimated number of facilities in the United States Server closets (900,000–1,500,000 facilities), Server rooms (50,000–100,000), Localized data center (10,000–13,000), Midtier data center (2,000–4,000), Enterprise-class data center (1,000–2,500).
13. Hwaiyu Geng, *Data Center Handbook,* 2015, New Jersey: John Wiley & Sons, p. 4

"These hyperscale data centers will grow from 338 in number at the end of 2016 to 628 by 2021. They will represent 53 percent of all installed data center servers by 2021.."
14. *Cisco Global Cloud Index: Forecast and Methodology, 2016–2021*, p. 7

"The EMEA and Asia-Pac regions continue to have the highest growth rates, though the US still accounts for almost 40% of the major cloud and internet data center sites. The next most popular locations are China, Japan, the UK, Germany and Australia, which collectively account for another 32% of the total."
15. Synergy Research Group, *Hyperscale Data Center Count Passed the 500 Milestone in Q3,* 2019

Data Center Size:
Mega (more than 9,000 rack yields - more than 22,500 m^2), Massive (more than 3,000 rack yields - more than 7,500 m^2), Large (more than 800 rack yields - more than 2,000 m^2), Medium (more than 200 rack yields - more than 500 m^2), Small (more than 10 rack yields - more than 25 m^2)
16. Mike Andrea, *Data Center Standards: Data Center Size and Density,* 2014, AFCOM

"A company like Facebook, eBay, or a large bank will have its own big storage data center - perhaps renting space next door, inside those DuPont Fabros aircraft carriers, or in a building all its own hundreds of miles away, where electric power is cheap, and there's enough fiber in the ground to keep the company connected."
17. Andrew Blum, *Tubes: A Journey to the Center of the Internet*, 2015, New York: HarperCollins Publishers, p. 96

Collocation or Multi-Tenant Data Centers (20%), Financial (17%), Telecommunications (14%), Software and/or Cloud Services (11%), Government (9%), Healthcare (5%), Manufacturing (5%), Utilities/Energy (5%), Retail/Distribution (4%), Education (4%), Insurance (3%), Media (2%), Transportation (2%)
18. Uptime Institute, *Global Data Center Survey,* 2018, p. 4

"In May 2018, we reported that agencies had collectively identified a total of 12,062 data centers in their inventories as of August 2017—an increase of about 9,000 data centers compared to OMB's October 2011 estimate."
19. *Uptime Institute Global Data Center Survey,* 2018, p. 4

Table 1: Number of Reported Tiered and Non-tiered Federal Agency Data Centers with Completed and Planned Closures through Fiscal Year 2018, as of August 2018
20. Mike Andrea, *Data Center Standards: Data Center Size and Density,* 2014, AFCOM

"A Data Center must be physically as well as environmentally secured making innovative and comprehensive use of architectural and engineering approach. The physical access to data center must be controlled and should be monitored by security personnel at the perimeter and through video surveillance."
21. Shishir K C, *Data Center Security & Virtualization*, 2018, New York: Touro College Graduate School of Technology, p. 14

"La redondance est au coeur de leur organisation : copie des données sur plusieurs sites, duplication des infrastructures électriques en cas de panne, réservoirs d'eau en cas de coupure pour la climatisation…"
22. Cécile Diguet & Fanny lopez, *L'impact spatial et énergétique des data centers sur les territoires*, 2019, Rapport Ademe, p. 8

"Encore plus discret, voire vraiment opaque, le leader mondial du cloud Amazon Web Services (AWS) construit des data centers à un rythme effréné dans le monde entier. […] Aucun soin n'est apporté au bâtiment, qui pourrait se confondre avec un entrepôt de stockage alimentaire ou une plateforme logistique, chapeauté de climatiseurs imposants et attelé de gros générateurs de secours au fioul."
23. Cécile Diguet & Fanny Lopez, *L'impact spatial et énergétique des data centers sur les territoires*, 2019, Rapport Ademe, p. 48

Data centers can be located almost anywhere that can provide significant amounts of power and connectivity to high speed national and international communications networks."
24. Hwaiyu Geng, *Data Center Handbook,* 2015, New Jersey: John Wiley & Sons, p. 90

"A striking characteristic of the constructed US long-haul fiber-optic network is a significant amount of observed infrastructure sharing."
25. Ramakrishnan Durairajan, Paul Barford, Joel Sommers, Walter Willinger, *InterTubes: A Study of the US Long-haul Fiber-optic Infrastructure*, 2015, London: Sigcomm, p. 2

"The submarine telecoms cables spanning our oceans are the information superhighways that form the 'backbone' of the global ecosystem of information and communication technologies (ICTs)."
26. Wayne Nielsen, et al., *Submarine Telecoms Industry Report*, *issue 8*, 2019, Submarine Telecom Forum, p. 6

"There were approximately 378 submarine cables in service as of early 2019, traversing roughly 1.2 million kilometers, connecting virtually all countries with a coastline."
27. Doug Brake, *Submarine Cables: Critical Infrastructure for Global Communications*, 2019, Information Technology & Innovation Foundation, p. 2

"The Virginia suburbs west of Washington, DC, were already a hot spot for many of the early commercial Internet providers, mainly due to the concentration of military contractors and high-tech companies in the area. 'It was the technology center', Feldman told me."
28. Andrew Blum, *Tubes: A Journey to the Center of the Internet*, 2015, New York: HarperCollins Publishers, p. 59

"Everything that happens online depends on the seemingly unassuming industrial architecture of the data centers — facilities housing the computer systems that store, control, and use data communications and connections, and in which human presence is increasingly incidental."
29. Ippolito Pestellini Laparelli, *Data Matter*, in Flash Art n° 326, Jun-Aug 2019, p. 55

"The layout and arrangement of a stone quarry depends on geology and topography. A quarry may be opened on a hillside or as an open pit. In either case, the rock may be worked as one face or may be made up of stepped working benches in a hill-slope."
30. David Gwyn & Christian Uhlrich, *Stone Quarrying Landscapes as World Heritage Sites*, 2014, p. 3

"Since a data center is heavily involved with electrical and mechanical equipments that cover 70–80% of data center capital costs (Fig. 1.4), oftentimes, a data center is considered an engineer-led project."
31. Hwaiyu Geng, *Data Center Handbook,* 2015, New Jersey: John Wiley & Sons, p. 8

32. Water Environment Federation, *Thornton Reservoir: From Active Quarry to 7.9 Billion Gallons of Wet Weather Storage,* 2016

"Effective space planning will ensure maximum rack locations and achieve power density with efficient and effective power and cooling distribution."
33. Hwaiyu Geng, *Data Center Handbook,* 2015, New Jersey: John Wiley & Sons, p. 8

Chatsworth 42U Rack – Dimensions and Specifications Table.
34. 42U Company, *42U Rack Dimensions & Specifications,* 2012

"The explosive costs represent one of the biggest energy expenses in stone crushing, ranging from 30 to 40% of the total annual energy costs."
35. Satyen Moray, *Energy Efficiency Opportunities in the Stone and Asphalt Industry,* 2005, ACEEE, p. 73

"Figure 2: Electric Energy Use Breakdown in a Crushing Facility:
Crusher equals 30% of the electrical energy, Conveyors 18%, Screens 13%, Pumps 12% and others."
36. Satyen Moray, *Energy Efficiency Opportunities in the Stone and Asphalt Industry,* 2005, ACEEE, p. 1

"Aggregates, whether crushed rock or sand and gravel, are heavy items. It is trivial to compute that beyond a certain distance range, the energy (and financial) cost of transport of material far outweighs the production energy."
37. Ian Hill, *A progress report on the Energy-Efficient Quarry project,* 2012, p. 130

38. RTVK, *The Geological Economics of Australia's Super Pit,* 2015

"Further, according to the Department of Energy, a typical government data center has 100 to 200 times the energy use intensity of a commercial building."
39. Uptime Institute, *Global Data Center Survey,* 2018, p. 6

"80% of the energy used by IT equipment (40%) and cooling equipment (40%). Powering the system use 10% and lighting 5%."
40. GreenPeace, *Powering the Cloud: How China's Internet Industry Can Shift to Renewable Energy*, 2019, p.5

"Equinix is the leading global provider of data centers, which means the majority of the world's Internet traffic passes through one of our data centers. To enable this digital highway, our data centers consumed more than 2,200 gigawatt hours (GWh) of electricity in 2014, the equivalent of powering 200,000+ average-sized US homes."
41. Equinix, *Turning the world's data green, Equinix Green Initiatives*, 2016, Green Data Center Brochure, p. 2

42. Equinix, *Equinix Compagny Fact Sheet*, 4Q 2017

"Geology is an excavation into the earth and its secrets that affords a view not only to the now-moment that unfolds into a future potential of exploitation but also to the past buried under our feet. Depth becomes time."
43. Jussy Parikka, *A Geology of Media*, 2015, London: Electronics Mediations, p. 13

"The oldest cables are on the bottom of the pile. 'It's almost like an ice core' Troyer said. 'As you dig down you're going to see sediment from certain time periods'."
44. Andrew Blum, *Tubes: A Journey to the Center of the Internet*, 2015, New York: HarperCollins Publishers, p. 97

"Aggregates are transported and stored several times (in most of the cases) before they are finally used in construction. Material is moved using all of the main transport modes: road, rail and water. Most primary aggregates are transported by road."
45. Sofiia Miliutenko, *Aggregate provision and sustainability issues in selected European cities around the Baltic Sea*, 2009, Stockholm: KTH, p. 23

"Submarine cables play a critical role in global interconnected networks, carrying about 99 percent of international communications traffic."
46. Wayne Nielsen, et al., *Submarine Telecoms Industry Report*, *issue 8*, 2019, Submarine Telecom Forum, p. 6

RETHINKING OBSOLESCENCE

60 LIFE CYCLE
Exhaustive Minerals and Inexhaustible Data

62 ENVIRONMENTAL SCARS
Disused Quarries and Data Center Ecological Imprint

68 SYSTEM OVERLAP
Network Opportunities and Water Management

76 BUILDING THE IMMATERIAL
Data Centers, The Quarries Of Tomorrow

Life Cycle

"Mineral deposits are not unlimited, but finite in mass or volume. Thus, every mine shall be closed down with expiration of ore reserves, after profitable mining operation during several tens years."
1. Kiyoshi Horikawa & Qizhong Guo, *Civil Engineering - Volume II,* 2009,Oxford: Eolss Publishers, p. 133

"A quarry's lifespan can range from under a decade to over 50 years' worth of resource supplying."
2. Catherine McCandless, *No Longer than just a Hole in the Ground,* 2013, MIT, p. 5

"2'000 entries pertaining to active mineral workings and a much larger number for inactive and former workings, totalling 193'470 entries."
3. *Directory of Mines and Quarries*, British Geological Survey, 2014

"The space created by quarries and mines exceeds the rate at which we fill them, so there will always be holes looking for uses."
4. Geoff Williams, *Old Mines and Quarries as valuable resource,* BSG, p. 11

"The traditional device for data storage is a disk drive, often referred to as a hard disk drive (HDD) with a mechanical rotating mechanism."
5. Hwaiyu Geng, *Data Center Handbook,* 2015, New Jersey: John Wiley & Sons, p. 408

"For cost reasons, SSDs are offered in lower storage capacity ranges, although the lower energy, lower temperature, and lower latency of SSDs are accelerating their adoption."
6. Hwaiyu Geng, *Data Center Handbook,* 2015, New Jersey: John Wiley & Sons, p. 408

"These hyperscale data centers will grow from 338 in number at the end of 2016 to 628 by 2021. They will represent 53 percent of all installed data center servers by 2021.."
7. *Cisco Global Cloud Index: Forecast and Methodology, 2016–2021*, p. 7

The lifespan of a quarry is short, because of the exhaustiveness of its mineral resources.[1] It takes only a few decades for a quarry to be obsolete.[2] For instance, 99% of them, are now abandoned.[3]

If resources get at some point depleted, the mark left behind oppositely stays forever. Quarry's afterlife therefore raises considerations about their rehabilitation. But most quarries fail to be filled. This situation gets even more problematic, knowing that the increasing needs for extractions outreach the rate of a quarry potential recovery.[4]

Most of the abandoned quarries therefore remain as open pits, revealing the geological strata of the earth. But there lies a significant contradiction: it takes only tens of years to extract minerals till their depletion, however formed by million years of sedimentation.

If quarries are defined by finite mineral deposits, data centers oppositely host non-exhaustible resources. The dematerialization of information makes data an infinite asset. It is the physical infrastructure that becomes obsolete.

In this regard, hardware must be replaced every decade, firstly to avoid dysfunctions, secondly for upgrades. Indeed, almost all data centers still use old hard-disk drives for storage[5] instead of the latest solid-state drives, for economic reasons: HDD are effectively way cheaper than SSD, but must be replaced more often.[6]

Unlike mineral resources, which get consumed faster than their own formation, data is growing exponentially. The more is consumed, the more there is. It is not a balanced system in which what is taken is compensated with something else. There, everything gets accumulated. In this regard, the number of data center is excepted to increase drastically due to the exploding amount of data generated anytime. For instance, hyper-scale data centers are planned to grow by 185% within a 5 years span.[7]

Environmental Scars

"Extraction of primary aggregates can substantially alter the landscape and affect groundwater reserves."
1. Sofia Miliutenko, *Aggregate provision and sustainability issues in selected European cities around the Baltic Sea,* 2009, Stockholm: KTH, p. 11

"Quarrying on any scale will change the surface water regime in and around the site during the production and after closure and restoration […] (to prevent adverse impacts on water quality or increases in flood risks)."
2. Ruth Allington & David Jarvis, *A Quarry Design Handbook*, 2014, p. 77

"Over the last several decades, much attention has been devoted to the reclamation and restoration of abandoned quarries."
3. Lucie Branova, Martin Balej, Pavel Raska, *Assessing the geotourism potential of abandoned quarries with multitemporal data*, 2017, Degruyter, p. 94

"Filling disused quarries with domestic waste is a common way of restoring them to previous ground level"
4.Geoff Williams, *Old Mines and Quarries as a Valuable Resource in Earthwise n°12*, 1998, British Geological Survey, p. 11

"Humans leave their mark, and the earth carries it forward as an archive."
5. Jussy Parikka, *A Geology of Media*, 2015, London: Electronics Mediations, p. x-xi

"Data centers are a fast-growing typology, largely responsible for the massive ICT industry global energy consumption. In fact, if data centers were a country, they would be the eleventh most energy consuming nation in the world, a ranking doomed to escalate at a frightening pace."
6. Ippolito Pestellini Laparelli, *Data Matter*, in Flash Art n° 326, Jun-Aug 2019, p. 55

"Les centres de données représentaient eux 2% de l'ensemble mondial, soit 420 TWh ou 60 tranches nucléaires. Les prévisions atteignent un maximum de 13% de l'électricité mondiale consommée par les data centers en 2030, et 51% pour le secteur informatique dans sa totalité, soit respectivement 1130 et 4400 réacteurs nucléaires. La démesure est chiffrée."
7. Cécile Diguet & Fanny, L'impact spatial et énergétique des data centers sur les territoires, 2019, Rapport Ademe, p. 16

"Researchers estimate that 73% of electricity consumed by China's data centers in 2018 was generated from coal and procured from the grid."
8. GreenPeace, *Powering the Cloud: How China's Internet Industry Can Shift to Renewable Energy*, 2019, p. 6

"Un data center de 15 MW peut utiliser jusqu'à 1,6 million de litres d'eau par jour (ou $1600m^3$)."
9. Cécile Diguet & Fanny Lopez, L'impact spatial et énergétique des data centers sur les territoires, 2019, Rapport Ademe, p. 16

Quarries present an alarming situation regarding the stability of our worldwide ecosystem. Responsible for the deep modification of the geological strata, extraction activities affect groundwater reserves.[1,2]

Once depleted, the soil conditions of a quarry don't present any longer viable opportunities for the nature to take back its rights over the affected lands. Even if laws imply the restoration of a disused quarry to its original and natural state,[3] many enterprises don't respect those political regulations, leaving the land, as deprived as it is or fill the remaining pits with domestic waste.[4]

Nevertheless, many quarries appear to be turned into lakes, thanks to natural processes. Indeed, when their lowest point is located below the water table surface, groundwater rises, filling them.

Finally quarries carry the mark we left over our environment.[5] They are therefore the most remarkable traces that support our societies in terms of material provenance. However, because of their difficult accessibility, they remain unnoticed, if not invisible to the majority of us.

On the other hand, data centers constantly increase their contribution to greenhouse emissions. If they were a country, they will be the eleventh most polluting nation in the world,[6] consuming 2% of the worldwide energy produced annually, a rate excepted to reach 13% by 2030.[7] This demonstrate a unprecedented jump of electric consumption, which in equivalence depicts the passage from 60 nuclear plants to 1130, within 12 years.

Even though big corporations tend to power their data centers with green renewable energies, 73% of the energy remain generated from coal and produced from the grid.[8]

Besides the powering of computational engines, cooling is a major responsible for this electrical consumption. Water being the most efficient way to keep servers cool, data centers therefore consume impressive amount of it.[9]

Left and right:
Henrick Spohler, 0_1 Dataflow, 2004

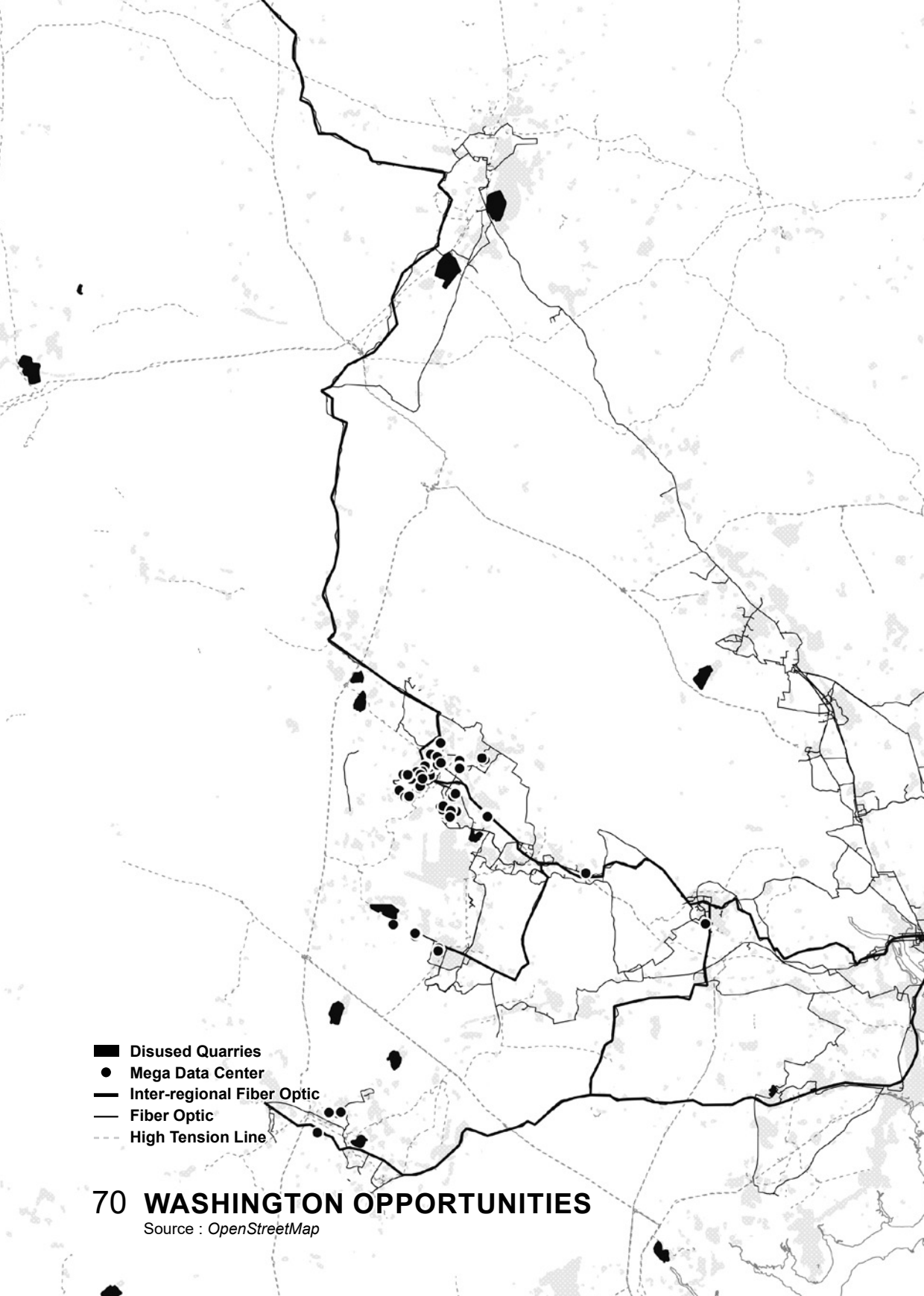
Next Page:
Laura Van Severen, Land, 2016

While many disused quarries naturally fill up with groundwater, data centers fill up with endless rows of server racks, urging to be cooled.

Close to important power supplies and sometimes to fiber optic networks, those quarry lakes present big opportunities for hosting data centers, water becoming a major asset on many points.

Used for cooling purposes, water appears to be the most efficient way to keep server's temperature at reasonable rates. Managed by dedicated infrastructures, water can provide sustainable redundant energy to data centers, indispensable to keep the system running in case of blackout. Surrounding the facility placed in the middle of a quarry lake, water constitutes a physical boundary, limiting access to a data center, hence reinforcing the security of its sensible stored data.

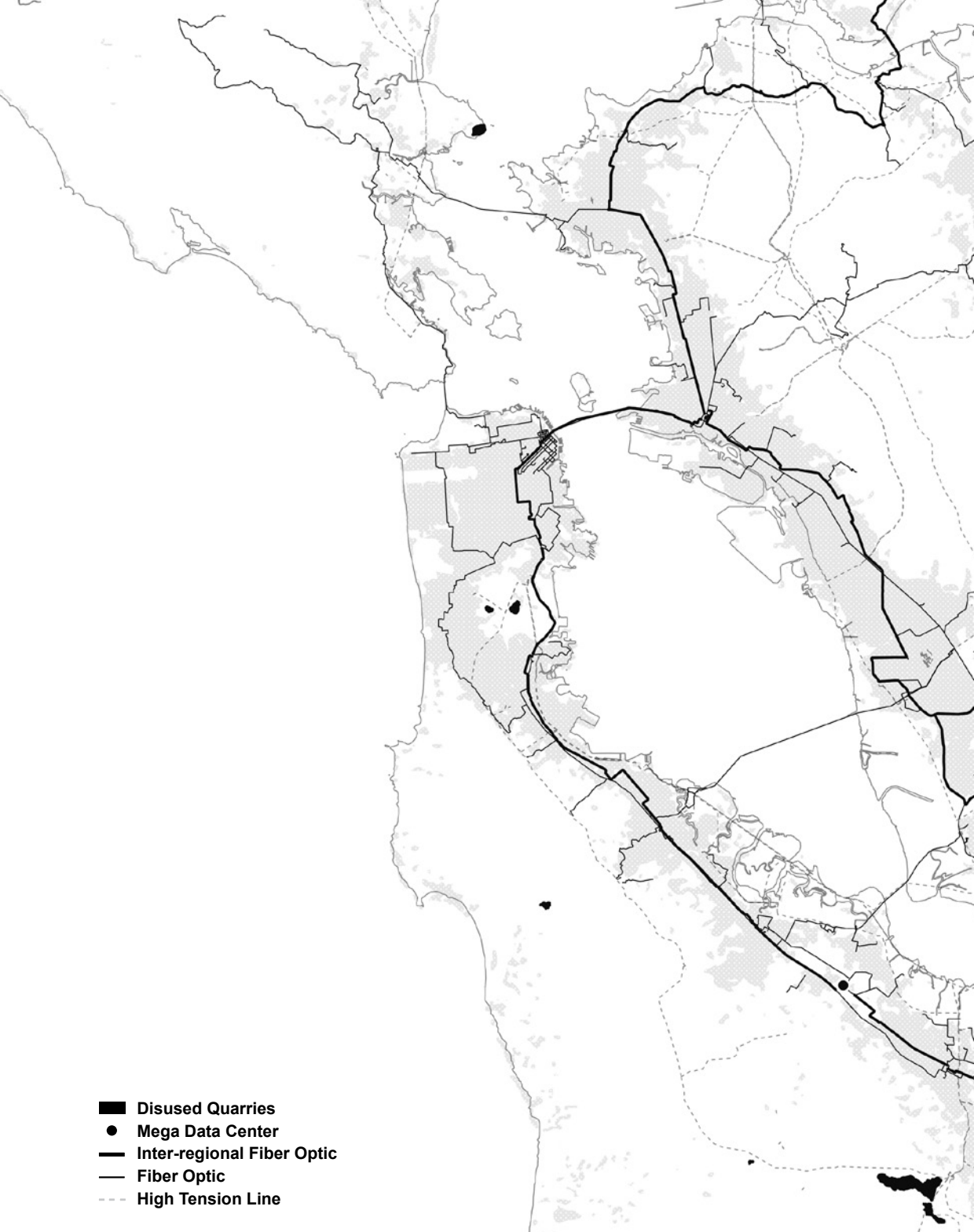
Overlapping depleted quarries with mega data centers constitutes therefore a new infrastructural cartography. One that takes deprived open pits as an advantage to reconfigure our technological imprint.



70 **WASHINGTON OPPORTUNITIES**

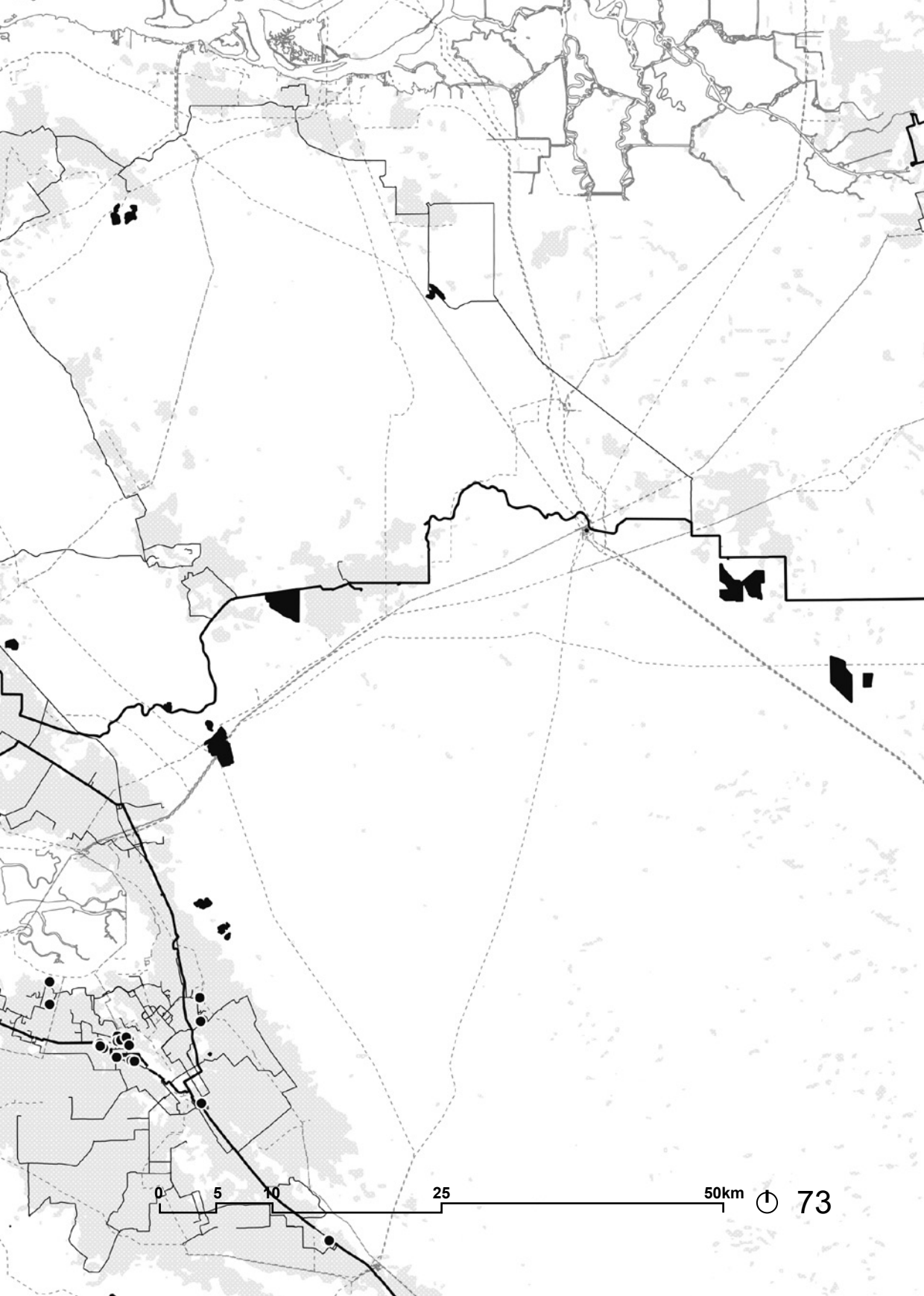
Source : *OpenStreetMap*

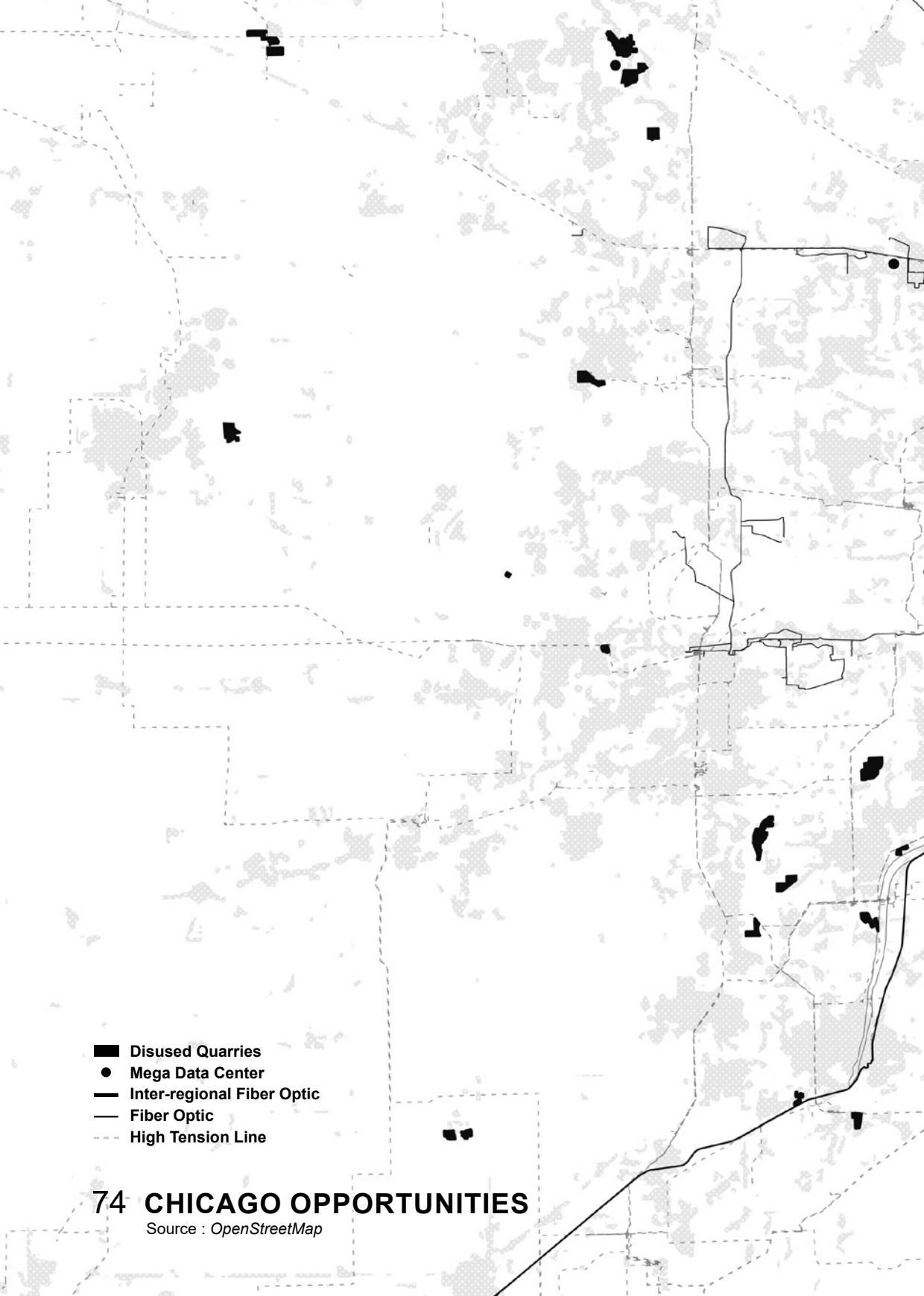
0
5
10
25
50km



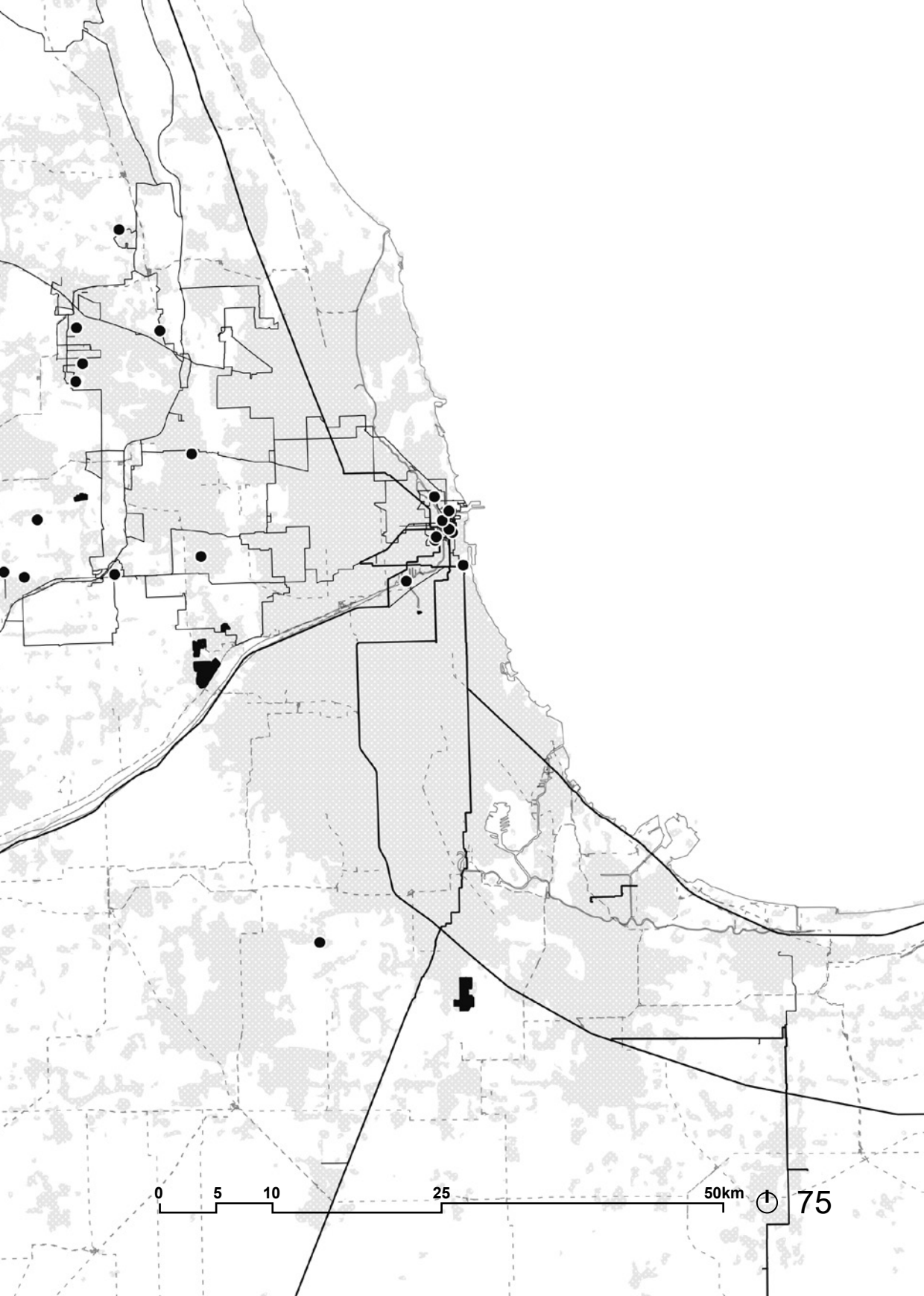
72 **SILICON VALLEY OPPORTUNITIES**

Source : *OpenStreetMap*


0
5
10
25
50km



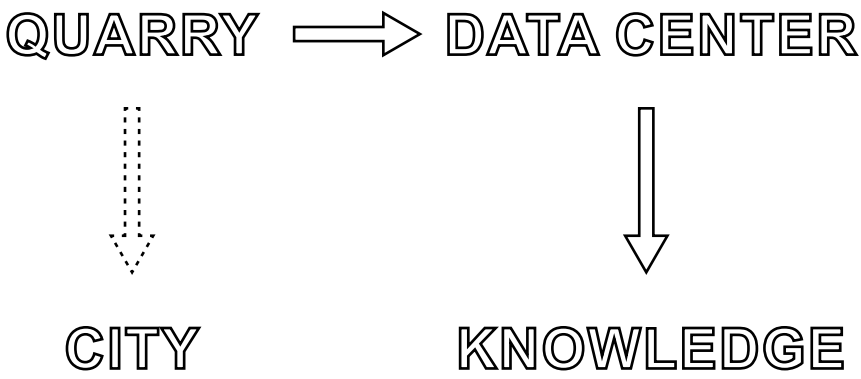
Source : *OpenStreetMap*


0
5
10
25
50km
75

The Quarries of Tomorrow

For thousands of years, we have been exhausting resources because of our extraction activities. We have been depleting quarries revealing earth history under our feet. Now has come the time to give those abused lands a second life, one based on inexhaustible resources: data.

Merging mega data centers with abandoned quarries undeniably offers a new paradigm, one combining the virtual knowledge of our time with the material history of our planet. Those reborn quarries, the ones of tomorrow will hence stand as the biggest archives our world has ever seen.


QUARRY
DATA CENTER
CITY
KNOWLEDGE

BIBLIOGRAPHY

Bibliography

Allington, Ruth and Jarvis, David, *A Quarry Design Handbook*, 2014

Andrea, Mike, *Data Center Standards: Data Center Size and Density,* 2014, AFCOM

Bélanger, Pierre, *Extraction Empire: 2017 - 1217,* 2018, Cambridge: MIT Press

Bélanger, Pierre, *Extraction Empire: 2017 - 1217,* 2018, Cambridge: MIT Press

Branova, Lucie; Balej, Martin and Raska, Pavel, *Assessing the geotourism potential of abandoned quarries with multitemporal data*, 2017, Degruyter

Brake, Doug, *Submarine Cables: Critical Infrastructure for Global Communications*, 2019, Information Technology & Innovation Foundation

Blum, Andrew, *Tubes: A Journey to the Center of the Internet*, 2015, New York: HarperCollins Publishers

Cameron, D.G et al., *Directory of Mines and Quarries*, British Geological Survey, 2014

Cisco Global Cloud Index: Forecast and Methodology, 2016–2021

Diguet, Cécile and Lopez, Fanny, *L'impact spatial et énergétique des data centers sur les territoires*, 2019, Rapport Ademe

Durairajan, Ramakrishnan; Barford, Paul; Sommers, Joel and Willinger, Walter, *InterTubes: A Study of the US Long-haul Fiber-optic Infrastructure*, 2015, London: Sigcomm

Eurosat, *Sectoral Analysis of employement by entreprise size class, Mining and Quarrying, (NACE Section B), EU-28,* 2016

Equinix, *Turning the world's data green, Equinix Green Initiatives*, 2016, Green Data Center Brochure

Equinix, *Equinix Compagny Fact Sheet*, 4Q 2017

Geng, Hwaiyu, *Data Center Handbook,* 2015, New Jersey: John Wiley & Sons

GreenPeace, *Powering the Cloud: How China's Internet Industry Can Shift to Renewable Energy*, 2019

Gwyn, David and Uhlrich, Christian, *Stone Quarrying Landscapes as World Heritage Sites*, 2014

Hill, Ian, *A progress report on the Energy-Efficient Quarry project,* 2012

Horikawa, Kiyoshi and Guo, Qizhong, *Civil Engineering - Volume II,* 2009,Oxford: Eolss Publishers

Hui, Yuk and Broeckmann, Andreas, *30 Years after Les Immatériaux: Art, Science, and Theory*, 2015, Menson Press

LeCavalier, Jesse, *The Rule of Logistics: Walmart and the Architecture of Fulfillment,* 2016, Minneapolis: University of Minnesota Press

Lefebvre, Henri, *The Production of Space*, 1991, Oxford: Blackwell

Miliutenko, Sofia, *Aggregate provision and sustainability issues in selected European cities around the Baltic Sea,* 2009, Stockholm: KTH

Mineral Education Coalition, *The Baby,* 2019

Moray, Satyen, *Energy Efficiency Opportunities in the Stone and Asphalt Industry,* 2005, ACEEE

Nielsen, Wayne, et al., *Submarine Telecoms Industry Report*, *issue 8*, 2019, Submarine Telecom Forum

Noah Harari, Yuval, *Homo Deus: A Brief History of Tomorrow*, 2015, Vintage

Parikka, Jussy, *A Geology of Media*, 2015, London: Electronics Mediations

Pestellini Laparelli, Ippolito, *Data Matter*, in Flash Art n° 326, Jun-Aug 2019

RTVK, *The Geological Economics of Australia's Super Pit,* 2015

Shishir, K.C, *Data Center Security & Virtualization*, 2018, New York: Touro College Graduate School of Technology

Smil, Vaclav, *Making the Modern World: Materials and Dematerialization,* 2014, New Jersey: Wiley publisher

Stanier, Peter H., *Quarries and Quarrying*, 1985, London: Shire Publications

Synergy Research Group, *Hyperscale Data Center Count Passed the 500 Milestone in Q3,* 2019

Uptime Institute, *Global Data Center Survey,* 2018

Water Environment Federation, *Thornton Reservoir: From Active Quarry to 7.9 Billion Gallons of Wet Weather Storage,* 2016

Whiston Spirn, Anne, *No Longer Just a Hole in the Ground, ,* 2013, MIT

Williams, Geoff, *Old Mines and Quarries as a Valuable Resource in Earthwise n°12*, 1998, British Geological Survey

Acknowledgment

First of all, I would like to express my special thanks to the Laba team for its support and guidance throughout this research process.

I convey my sincere gratitude to professor Harry Gugger, director of Laba, for its advices and wisdom in the role of *professeur responsable de l'énoncé* and as *directeur pédagogique*.

My thanks equally go to Augustin Clement for its moral support and close supervision as *Maître EPFL*.

Finally, I would like to deeply thank my girlfriend Elisabeth Terrisse De Botton for her help and relief during this long and sometime perilous journey.