STEPHAN SIGRIST | NICHOLAS BORNSTEIN | JULIA STRICKER | GERD VOITH
WITH ILLUSTRATIONS BY MATTHIAS GNEHM

THE LABORATORY OF THE FUTURE

WHY THE RESEARCH OF TOMORROW
WILL BE AUTOMATED, DECENTRALISED AND INTERDISCIPLINARY.
AND WHY HUMANS WILL ALWAYS REMAIN CENTRAL.

W.I.R.E.
[WEB FOR INTERDISCIPLINARY RESEARCH & EXPERTISE]
—
THINK TANK FOR BUSINESS, SCIENCE & SOCIETY

SAVIDA AG
BY OFFICE VOITH

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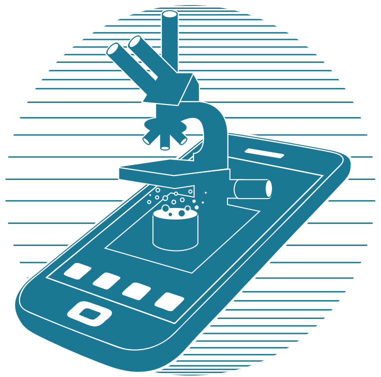
By Stephan Sigrist, Julia Stricker, Nicholas Bornstein & Gerd Voith
With illustrations by Matthias Gnehm

STUDY PREPARED ON BEHALF OF SAVIDA AG



EXECUTIVE SUMMARY

This brief study analyses the present and future frameworks for the operation of biomedical laboratories. A model which explores a lab's most important functions for the workers and the key dimensions which structure it was developed on the basis of expert interviews, an interdisciplinary workshop and desk research. According to this schematic model, not only the spatial and architectural dimensions are relevant, but also the prevailing research culture and available resources.

In a second step, long-term developments were analysed which influence biomedical labs today and will change their operating frameworks in the long term. For example, a large proportion of wet lab work will take the form of modelling and simulation in the future, which will lead to a redistribution of labour between man and machine. Further developments with a fundamental impact on the lab of today are geopolitical power shifts, the miniaturisation of lab equipment and the increasing complexity of scientific research.

A targeted response to these developments is needed. The study has produced six recommendations that should be taken into account in the planning and design of a future-oriented lab. As work becomes increasingly individualised and decentralised, ensuring social interaction will be one central issue. In addition to concrete measures, however, the role and self-perception of labs in an innovation-driven society have to be fundamentally re-examined and labs have to enter into dialogue with the public. The study closes with three scenarios that cast a glance into the distant future, revealing where the lab of the future could be headed and the implications for the individual, science and society.

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1

INTRODUCTION

THE OPERATING FRAMEWORK FOR RESEARCH IS CHANGING, BUT THE LABS OF TODAY ARE STILL BASED ON YESTERDAY'S INFRASTRUCTURE AND CONCEPTUAL MODELS.

Scientific research is subject to major social, economic and cultural changes, but the role and function of labs have been slow to change since World War II and their structures and ways of working have remained largely the same. However, mindsets have recently started to change. Open lab layouts, shared working areas, the use of new technologies and the opening up of research institutions to the public bear witness to the ongoing transformation. This development reflects a culture shift in the scientific world: research is gradually being perceived more as a collaborative and interdisciplinary endeavour, communication and creativity are being encouraged. The common conception of a modern lab is therefore moving further and further away from the model of the compartmentalised lab of the post-war era.

As an integral part of scientific research, labs thus present public and private research institutes with major challenges, because they have the task of providing the optimum working conditions for research. However, the changes in research are taking place at great speed, complexity is increasing because of new research questions and the emergence of large data volumes, and automation has become established in the biomedical lab as it has elsewhere. This means that changes in future environments have to be anticipated more than ever in the planning and construction of laboratories. The following questions therefore arise: what form will laboratory architecture take in the medium- to long-term future? And what will the most important factors of influence be?

On the basis of a schematic model, this brief study summarises relevant dimensions for the biomedical lab of the future and sets out areas for action. The aim of the study is to identify long-term developments for the biomedical research laboratory and to design scenarios for labs of the future. These should help to illuminate perspectives on future research architecture and at the same time provide starting points for a deeper scientific and practical examination of the topic. The theoretical analysis of the framework for future labs concludes sub-project I. Sub-project II will use the results to test the practical implementation of the findings in pilot projects.

This research project would not have been possible without the active support and input of a number of experts, researchers and practitioners. We would like to thank them very much at this point for the time and commitment that they devoted to answering our questions and taking part in the workshop.

BRIEF & AIMS OF THE PROJECT

The W.I.R.E. think tank conducted a research project on the laboratory of the future on behalf of Savida AG. This comprised the analysis of a laboratory's relevant functions and dimensions, the identification of the most important areas for action for planners and builders of future laboratories and the development of long-term visions. The result of this work is presented in condensed form in this brief study, culminating in a schematic outline of three possible scenarios as to how labs may develop in the long term. The brief study features an interdisciplinary approach in order to incorporate aspects beyond design and architecture.

DEFINITION OF THE RESEARCH TOPIC:
The project focused on an analysis of the future framework for the operation of public and private biomedical research labs. Production, diagnostic and pure training labs were not considered since they pursue different goals by their nature and functions.

The following research aims were pursued in the study:

AIM 1:
Clarify starting position and create transparency: what functions does lab work include?

AIM 2:
State relevant dimensions that structure lab work.

AIM 3:
Define the areas for action and identify the drivers of change.

AIM 4:
Develop visions, excluding obstacles found in the present day.

EXPERTS SURVEYED

DR MARC DUSSEILLER
Nanoscientist and cultural event organiser, co-founder of Hackteria.org

PROF. DR GERD FOLKERS
Collegium Helveticum of ETH and the University of Zurich

DR VIREN JAIN
Senior Research Scientist with Google, California. Former Research Group Leader on the Janelia Farm Research Campus of the HHMI

PETER JAMES
Director of the S-Lab Initiative: Safe, Successful and Sustainable Laboratories, London

GERD KUCHENBECKER
Author of the book "Ein Labor für morgen" ["A Lab for Tomorrow"]. Former lab planner with Schering AG.

BOB MCGHEE
Former institute architect with the Howard Hughes Medical Institute (HHMI)

DR NEVILLE SANJANA
Post-doctoral student at the Broad Institute of MIT and Harvard

DANIEL WENTZLAFF
Nissen Wentzlaff Architekten, Basel

WORKSHOP PARTICIPANTS

NELE DECHMANN
Architect, Zurich

DR MAREIKE HEINZEN
Senior Research Scientist, Chair of Innovation and Technology Management, ETH Zurich

PROF. DR
JÖRG RAINER NOENNIG
Professor of Knowledge Architecture, TU Dresden

FRANK M. RINDERKNECHT
Founder and owner of Rinspeed Inc., Zumikon

ANJA SAXER
Lab technician, University of Zurich

PROF. DR
GISBERT SCHNEIDER
Professor of Pharmaceutical Sciences, ETH Zurich

DANIEL WENTZLAFF
Nissen Wentzlaff Architekten, Basel

DR AMREI WITTWER
Senior Assistant, Collegium Helveticum of the ETH and the University of Zurich

EVERT YPMA
Design Research, Zurich

METHOD

The complexity of the subject area required a multi-stage approach. This comprised desk research, interviews with experts and a workshop with participants from different disciplines.

1. KICKOFF
Meeting to determine key points of project

- Content focus
- Objectives
- Schedule

2. RESEARCH PHASE I
Analysis of starting position and change drivers, initial thinking about vision

- LITERATURE RESEARCH: developments in the area of biomedical labs, functions and the dimensions influencing them, basic principles of historical development lines, current innovative examples
- INTERVIEWS with eight experts from the following professional fields: lab planning, architecture and research
- ANALYSIS of the drivers of change
- LAB VISIT at the Novartis Campus Basel with first interim report
- WORKSHOP: interdisciplinary workshop with architects, lab design specialists, artists, designers and user-side representatives.
  Presentation of initial analyses and change drivers, possible visions formulated together

3. INTERIM MEETING
Results of first research phase presented and discussed using a concrete example

- DISCUSSION OF RESULTS of first research phase and of the visions
- LAB VISIT at the ETH Hönggerberg: with Gisbert Schneider, Daniel Wentzlaff, Gerd Voith.
  Discussion of results to date based on this concrete example

4. RESEARCH PHASE II
Concept finalised and final report written

- CONCLUDING RESEARCH
- DEVELOPMENT OF A SCHEMATIC MODEL of a biomedical lab, consisting of the three dimensions of space, culture and resources, resulting from the literature research, expert interviews and workshop
- FINALISATION OF THE FINAL REPORT

5. PROJECT
Project Phase I completed, Project Phase II planned

- SUBMISSION OF THE FINAL REPORT for Project Phase I
- NEXT STEPS DETERMINED

2

STARTING POSITION

LABS ARE CHARACTERISED BY THE DIMENSIONS OF SPACE, CULTURE AND RESOURCES AND HAVE THE GOAL OF PROVIDING AN OPTIMUM FRAMEWORK FOR RESEARCH

Labs are an integral part of biomedical research, providing the physical space needed for the production of knowledge. They perform a variety of functions, from offering safe working environments to enabling an exchange of information. Three dimensions are of overriding interest in capturing the diversity of a lab's tasks: the spatial design, cultural factors and the availability of resources. The model created by W.I.R.E. is explained below.

SCHEMATIC MODEL OF A LAB

The overriding goals of a lab are to generate and further develop knowledge. To reach these goals, it makes physical space and a certain number of functions available (SEE 2.2). As a spatial and conceptual location, the lab is structured by the three dimensions of space, culture and resources (SEE 2.3).

A. CREATING KNOWLEDGE

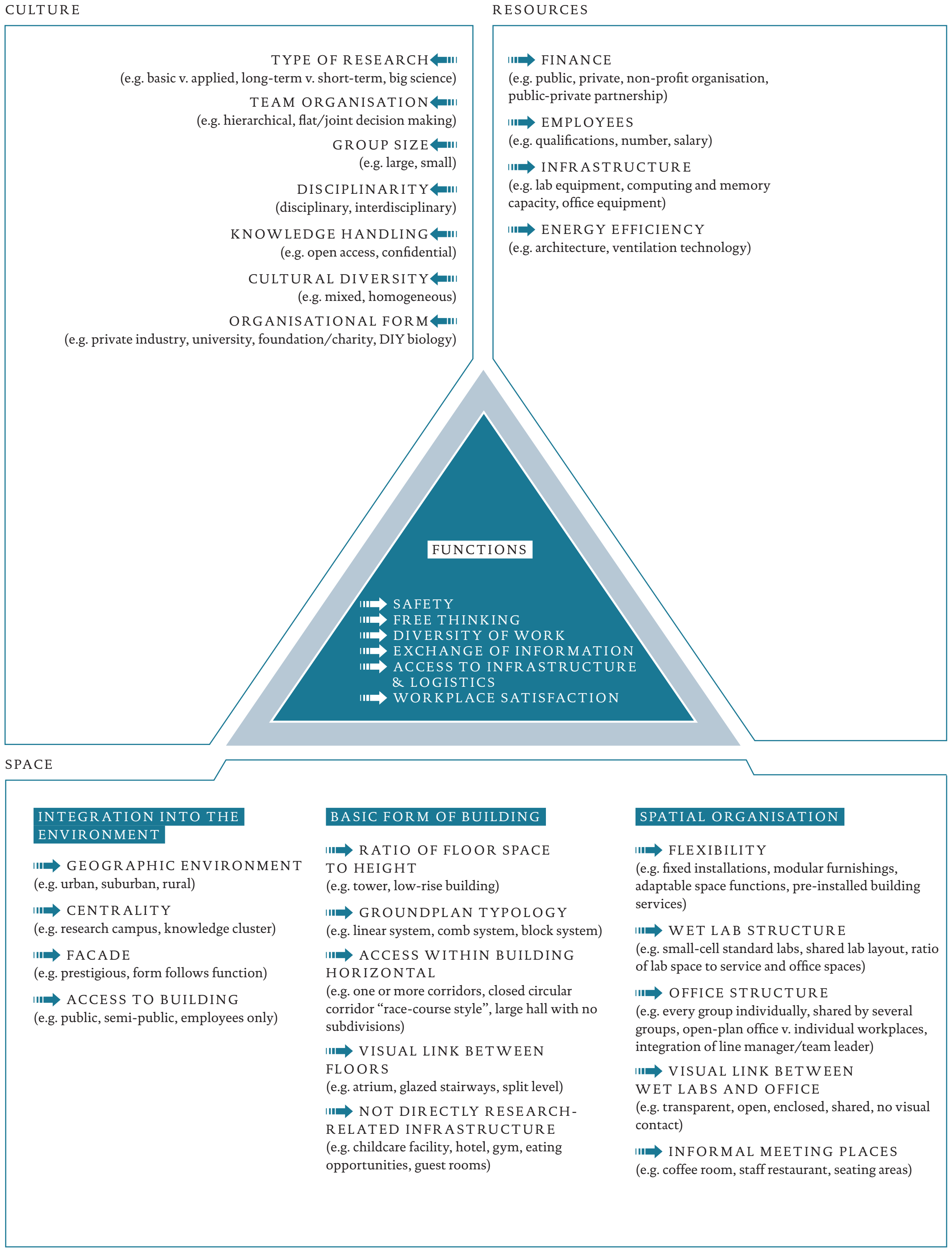
In research, traditional knowledge is challenged and new knowledge created. This, in turn, leads to new questions and is itself challenged.[1] This process of knowledge creation in the lab can be illustrated by the cycle below (FIG. 1).

In biomedical research, this process traditionally means hypotheses being tested or new methods implemented on the basis of experiments in the wet lab. The results are interpreted to produce new insights or refute previous findings. New goals and questions are then developed.

FIG. 1 :
The knowledge creation process
Source: Own design

B. FUNCTIONS

The lab provides the structure where different functions are enabled. The following functions are central (SEE ALSO FIG. 2):



DIVERSITY OF WORK

Biomedical research is a mix of work in the office and in the wet lab. Different steps in the research process generate different spatial design requirements, a lab's spatial range should reflect the spectrum from withdrawn concentration to teamwork.[2] It must be possible to adapt the working environment to these needs and provide researchers with different workplaces – coffee stations or staff restaurants can also be used as working areas.[3]

EXCHANGE OF INFORMATION

Exchanging information is a core element of knowledge work. The knowledge creation process is fostered by encouraging channels and opportunities for interaction.[4] Communication and interaction may be organised, for example in meetings or research colloquia, or informal and spontaneous. The great importance of visibility has to be seen in this context, it is considered to be the key to communication.[5] Personal discussions are still thought of as the "gold standard", despite the increasing possibilities offered by digital communication.

WORKPLACE SATISFACTION

Researchers have to feel happy at the workplace. A prestigious building that supports employees' different lifestyles and work styles and provides a pleasant working atmosphere can contribute to workplace satisfaction and help to create an identity. Modern building envelopes and interior designs that take not only functional requirements but also those of form into account give researchers a sense of being valued and contribute to staff retention.[6] Finally, the integration of the building into its immediate environment and its infrastructural accessibility also play an important role.

SAFETY

Lab work includes handling hazardous substances such as toxic chemicals, viruses, micro-organisms and radioactive materials. The safety and hygiene regulations for the construction and operation of a research building are therefore rigorous. Depending on the hazard potential, people may be forbidden to enter wet labs unless they are wearing special clothing, goggles and gloves; certain manipulations are only carried out in the controlled atmosphere of a laboratory hood for hygiene and safety reasons.

← FIG. 2:
Model of the functions and dimensions of a laboratory
Source: Own design.
Based on Braun, Grömling 2005; Rubin 2006; Howard Hughes Medical Institute 2003;
interviews with D. Wentzlaff, R. McGhee, P. James, G. Kuchenbecker

ACCESS TO INFRASTRUCTURE
Biomedical research is technology-intensive. To conduct their experiments, researchers need equipment ranging from pipettes through laboratory hoods to measuring instruments such as spectrometers. Refrigerators, electron microscopes and other large machines are often installed separately in service rooms. Digital infrastructure – hardware and software – is central to lab work, since researchers need access to analysis software and corresponding data storage and computing capacity.

FREE THINKING
To allow and foster innovation and invention, the lab has to provide space and time for reflection and the generation of ideas. In addition, researchers should be given the freedom to pursue even those ideas with uncertain prospects of success, which may not lead directly to publishable results or the development of a product. This approach can be supported by decisions and structures embedded in the right research culture.[7]

"THE WAY I WOULD DISTINGUISH A LABORATORY FROM ANY OTHER WORK ENVIRONMENT IS THAT IT'S MORE UNSTRUCTURED. IT IS A PLACE WHERE YOU CAN PLAY WITH NEW IDEAS AND EXPLORE THEM WITHOUT BEING NECESSARILY CONCERNED ABOUT PRODUCING A USEFUL PRODUCT TOMORROW OR THE NEXT DAY."

Viren Jain

C. DIMENSIONS

The lab is characterised by three dimensions. These are explained in brief below and their constituent factors illustrated in FIG. 2.

CULTURE
Research culture determines the way an institution normally pursues research, i.e. the way it creates and communicates knowledge. It is influenced by a large number of factors: from the hierarchy prevailing in a group, the size of the group and the type of research questions to the institution conducting the research.

RESOURCES
Biomedical labs have a high demand for material resources. In addition to financial resources, the availability of qualified personnel and access to infrastructure play an important role.

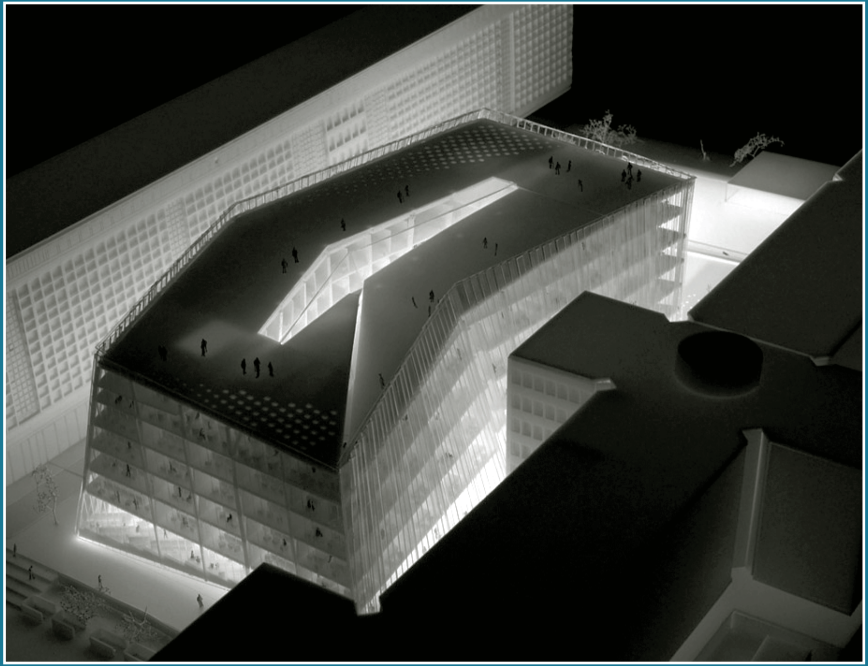
SPACE
Whether intentionally or not, the form and design of the lab reflects the culture and priorities of the organisation that is housed within it.[8] Conversely, spatial interventions can support desired behaviour, for example by promoting communication among employees.[9] The dimension of space is divided into three categories: the building in its environment, its basic form and the organisation of the space.

STATE OF THE ART IN LAB ARCHITECTURE

#1 THE ADAPTABLE, COMMUNICATION-FOCUSED LAB

#2 THE FLEXIBLE LAB FOR INTERDISCIPLINARY GROUPS

#3 THE LAB AS A PUBLIC PARK IN THE URBAN CONTEXT



STATE OF THE ART IN LAB ARCHITECTURE #1:

THE ADAPTABLE, COMMUNICATION-FOCUSED LAB

Name: James H. Clark Center
Architect: Foster and Partners Opened: 2003
Institution: Stanford University
Location: Stanford, California, USA

Stanford University's Bio-X institute at the James H. Clark Center brings together physicians, biologists, chemists, engineers, physicists and information scientists to perform research into important biomedical problems.

The building, designed by Norman Foster, makes a clear stride away from classic lab architecture. All corridors are on external balconies, allowing a more flexible allocation of space on the inside. The labs are designed as open rooms facing onto the inner courtyard and occupying almost the entire floor. Wet lab and office work can be carried out there in parallel. All tables and benches are mounted on rollers so that the furniture can be quickly adapted for different research teams. Small units can be separated spatially and acoustically as required. The façade is of glass and enables a clear view from the balconies into the lab rooms. Visibility is systematically encouraged as a basis for communication and interaction.[10,11]

In the inner courtyard, a restaurant offers room for informal discussions.[12] The building is placed between a hospital and the rest of the campus, thus facilitating encounters between researchers and students from different academic disciplines.

"ONE OF THE REAL DRIVING PRINCIPLES FOR JANELIA FARM WAS VISIBILITY [...]. ONCE YOU SEE SOMEONE YOU MIGHT ALSO GO THERE AND TALK TO HIM [...]. VISIBILITY IS THE KEY TO INTERACTION."

Bob McGhee

STATE OF THE ART IN LAB ARCHITECTURE #2 :

THE FLE XIBLE LAB FOR INTERDISCIPLINARY GROUPS

Name: Janelia Farm Research Campus
Architect: Rafael Viñoly Architects Opened: 2006
Institution: Howard Hughes Medical Institute (HHMI)
Location: Ashburn, Virginia, USA

The Janelia Farm Research Campus is an experiment in scientific culture: the intention is to foster interdisciplinary collaboration by forming small research groups of two to six members. The basic idea is taken from two iconic labs: AT&T's Bell Laboratories and the Medical Research Council Laboratory of Molecular Biology in England. The thing that distinguished both of those labs from other institutions of their day was their small research groups consisting of fewer than six researchers.[13]

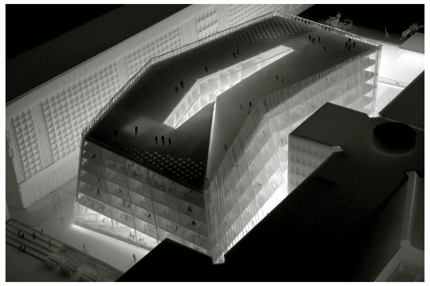
The crucial structure in Janelia Farm's research building is the central corridor with a restaurant or a bar at each end. Along the corridor, wet lab workplaces are arranged on one side and small office clusters on the other. While the office rooms are designed to improve collaboration within the group, the open wet labs shared by several groups are intended to facilitate interaction between groups. Passers-by can see into both the labs and the offices from the corridor. There is also a visual connection between the offices and the wet labs across the glazed-in corridor.[14]

Another key focal point was flexibility: wet lab rooms can be easily converted into service rooms or offices. While most of today's lab buildings have service space and lab space in roughly equal proportions, Janelia Farm has around 50% more service space, which promises additional flexibility to adapt to future requirements.[15]

Because Janelia Farm is far away from other university or private research institutes, high priority is given to bringing the scientific community to the campus by holding regular conferences. A hotel accommodates the visitors on site. The researchers themselves can also live on campus and have the benefit of childcare facilities.

STATE OF THE ART IN LAB ARCHITECTURE #3 :

THE LAB AS A PUBLIC PARK IN THE URBAN CONTEXT



Name: Paris PARC
Architect: BIG mit OFF Opened: to be confirmed
Institution: Université Pierre et Marie Curie
Location Paris, France

The new building at the Université Pierre et Marie Curie in Paris, which is still in the planning stage, is intended to bring together researchers from different disciplines, start-ups and established companies under one roof. In addition, France's leading science university is to gain a prestigious building demonstrating its openness and international character, which also establishes contact with the city.

It is planned to open the building to the public and allow access to a rooftop that is laid out as a park. The stairway leading to the roof terrace will allow visitors to see the labs and their everyday routine. The divisions between the labs will be transparent to ensure a visual link between different workplaces. In addition, the ground floor will hold a public bookshop, a café and exhibition areas.[16]

3

DRIVERS OF CHANGE

LONG-TERM DEVELOPMENTS IN SOCIETY, SCIENCE AND BUSINESS WILL CHANGE THE FRAMEWORK OF THE LAB OF THE FUTURE: LABS WILL BECOME SMALLER AND GLOBAL, AND HUMANS WILL BE PUSHED OUT.

From technological innovations to social upheavals, a number of forces are currently acting on modern labs. They influence the way research is carried out and therefore the planning and architecture of biomedical labs. The changing framework for lab operation is described below.

THE RISE OF NEW SCIENCE HOTSPOTS

While the centre of biomedical research was located in the Western world for many years and researchers poured into Europe and North America, talent is now increasingly migrating in other directions.[17] Driven by massive government investments, attractive science hotspots are developing in China, Singapore and Hong Kong. China's research expenditure has been rising by two-digit rates for years, while that of the USA and Europe in 2013 increased slightly but remained below inflation.[18] If this trend continues, China's research and development spend will overtake that of the USA in the year 2022.[19]

The industrialised countries are increasingly focusing in their research and development on opening up Asia. For example, European and American universities are entering into more and more partnerships with Asian universities. One programme in the USA is therefore designed to expand student exchanges and bilateral research cooperation with China.[20] The major pharmaceutical companies of the industrialised world, from Roche and Novartis to Pfizer, are also strengthening their presence in Asia. They are not just opening up the growing Asian market for established products, but conducting research into the specific medical problems of local populations and searching for new forms of therapy.[21] The Novartis Institute for Tropical Diseases in Singapore, for example, is a research institute funded jointly by Novartis and the Singapore Economic Development Board whose sole purpose is to look for new drug-based therapies for tropical diseases.

"WITH THE BALGRIST CAMPUS, WE WANTED TO CREATE A BUILDING WHERE PEOPLE MEET AND GET INTO CONVERSATION WITH EACH OTHER. THE OPEN LAB AND OFFICE STRUCTURES AND THE SHARED FACILITIES SUPPORT THAT."

Daniel Wentzlaff

A much-discussed example of the rise of Chinese science is the BGI (the former Beijing Genomics Institute) – with 178 sequencers the largest genetics institute in the world and responsible for at least a quarter of global DNA analyses. The institute performs sequencing for clients all over the world, is expanding into Europe and has a clear ambition to develop into a first-class research centre rather than remaining a mere service laboratory.[22] Another example is Biopolis, founded in Singapore in 2002, which is now established as a desirable research site in the field of biomedical research. In addition to the star architecture by Zaha Hadid, contributing factors here are major government investments and a research-friendly regulatory situation, for example in the area of stem cell research.[23, 24]

CONSEQUENCES FOR LABS:

1. Attractive workplace design is becoming an ever more important factor in the global competition for talent.

2. The lab building is taking on more and more of the function of lending prestige, giving the institution an external identity and promoting employees' sense of belonging.[25]

3. To take account of the global nature of the research community, research institutes and buildings are being planned so that they can be let or sold on if the organisation moves on. High demands are therefore made on infrastructural flexibility.[26]

4. A trend is perceptible in the emerging economies for the financing of new research institutes to be shared by public resources and the private sector (PPP).[27]

INCREASING COMPLEXITY

Innovation in the field of medicine has changed. Whereas in the 1990s even minor improvements led to big-selling new products, today the mechanisms of more and more complex disorders have to be understood in order to produce a block-buster.[28] For example, research is now being carried out into the way hundreds of genes and proteins interact in diseases such as Alzheimer's or Parkinson's.[29] Refined technologies are leading to new insights and expanding researchers' scope. Collaboration among different disciplines is becoming an ever more decisive factor in answering the increasingly complex questions.[30]

In addition, more and more diseases are becoming curable or at least treatable. As medicine becomes very highly specialised, progress becomes possible in fields that were previously beyond the reach of therapy. Furthermore, with the rise of the emerging economies the spectrum of diseases is changing: in the year 2012 the emerging economies accounted for 57% of the 14 million people diagnosed with cancer.[31] Ultimately, however, treatment is also becoming more complex because of increasing regulatory requirements. Reasons for the increasing government regulation and supervision of health care systems in the industrialised countries are, firstly, increasing cost pressure and the associated higher demands on measuring and safeguarding efficiency and quality. Secondly, with the demand for quality assurance comes an increase in data volumes – even though the efficient analysis and use of this data often fails due to non-standardised processes and systems.

"FACILITATING INTERACTION IS A CHALLENGE PARTICULARLY IN THE WORLD OF THE LABORATORY. THERE ARE NOT ONLY MANY PHYSICAL BARRIERS IMPOSED BY THE TECHNICAL INFRASTRUCTURE AND SAFETY RULES, BUT ALSO A LOT OF CULTURAL AND ORGANISATIONAL HURDLES THAT IMPEDE THIS SCIENTIFIC INTERACTION PROCESS."

Peter James

CONSEQUENCES FOR LABS:

1. As a result of the increasing complexity, work becomes inefficient, expensive and longer-term. This makes it more difficult to plan medical research.

2. Interdisciplinarity is becoming the new standard in biomedical research. It can be fostered by open lab layouts for shared use.

3. Visibility and informal meeting places in a lab building support efficient and effective collaboration among researchers from different disciplines.

4. Smaller research groups are becoming established; collaboration with other groups and cross-disciplinary projects are now inescapable.[32]

MINIATURISATION IN THE LAB

The miniaturisation of lab equipment will have a major influence on the lab of the future. Machines whose first-generation models filled rooms can now be comfortably accommodated on a table. This is making the set-ups for experiments more and more compact. The trend now extends to actual chemical experiments, basic functions of a chemical lab are being combined on a single chip. A series of reactions and analyses are carried out in the smallest possible space, using the minimum amount of chemicals. Experiments on these "labs-on-a-chip" can be monitored and recorded very precisely.[33]

This technology will become very important, and not only in research labs. It can also be used to make medical diagnostics more mobile and to take this function to remote areas.[34] For example, a recently developed lab-on-a-chip makes it possible to measure an important parameter for assessing the progress of an HIV infection with a simple drop of blood. HIV therapy for patients in emerging economies can thus now be based on criteria commonly used in industrialised countries while also saving the cost of complex equipment.[35]

Complex three-dimensional models of human organs, built from cells, that are stored on microchips are going in a similar direction. These "organs-on-a-chip" could soon be used to model diseases in an early stage of drug development. They unite more aspects of the disease than traditional cell cultures and therefore offer the prospect of being able to understand a substance better even before the stage of experiments on animals.[36] In the best case, such experiments may be avoided or at least reduced in future as a result.[37] For example, there is hope of new research insights into the formation of metastases in breast cancer cells.[38]

CONSEQUENCES FOR LABS:

1.
Lab work will need less space and wet labs will become smaller. Building services, particularly the air exchange rate, can be reduced because smaller amounts of substances will be needed.[39]

2.
The miniaturisation of experimental setups will lead to savings in chemicals.

3.
In the medium term, the organ-on-a-chip technology could revolutionise lab work, because it is more effective, lower-cost and entails fewer experiments on animals.[40]

AUTOMATION AND ROBOTISATION

Automation has led to enormous efficiency improvements and cost savings, particularly in production. But it is also becoming more and more important in research: the sequencing of the human genome would not have been possible without automated work processes and today's drug development depends on high-throughput processes in which biochemical, genetic or pharmacological tests are performed automatically on tens of thousands of molecules.

There are indications that the researcher of the future will not only be relieved of manual tasks, but that machines will increasingly take over creative tasks as well. Learning robots already exist that formulate hypotheses, test them experimentally in the lab, analyse the results independently and deduce the next hypothesis from them. The robot researcher Adam, developed in England, has already made its own first discoveries without human aid.[41] According to experts, it can work at the level of a doctoral student, but more efficiently. Artificial intelligence is becoming more and more important, particularly in view of ever larger data volumes which have become difficult for humans to capture.[42] Robots can relieve researchers of routine work and give them the chance to use their time for reflection and analysis.[43]

CONSEQUENCES FOR LABS:

1. Humans will be exposed less often to hazardous substances, which will make work safer and lead to savings in building services.

2. Routine work performed by robots is generally less expensive than the same work done by humans. In the longer term, this will lead to lower research costs.[44]

3. Research will tend to focus on incremental progress and will be increasingly automated. Freeing people from a large proportion of the routine work will create more scope for critical thinking.

"RESEARCHERS AND THEIR WORK CANNOT BE STANDARDISED. THE DIVERSITY OF THE WORKERS AND THEIR DIFFERENT LIFESTYLES AND WORKING STYLES SHOULD NOT BE PREVENTED, BUT ACCEPTED."

Gerd Folkers

EVER MORE DATA, EVER FASTER

Like other areas, the biomedical sciences are increasingly typified by large data volumes and methods based on complex algorithms. Fast and cost-efficient processes, from imaging to DNA sequencing, are generating more and more data. Following the work on the human genome, the "proteome", the entire set of proteins in a cell or organism, and the "connectome", all neural connections of the brain, are now being decoded. Electronic medical records, which are becoming increasingly common in hospitals, are also leading to an accumulation of large volumes of clinical information that is of interest to research.

Statistical methods are one key to the understanding and use of these data. Today, molecular reactions, entire cells and organisms can be digitally simulated.[45] Models of individual cells are already making it possible to carry out part of the drug development process in silico, minimising expensive and complex experiments in the wet lab.

A German research network is currently working on a dynamic mathematical model of a liver that maps the physiology, morphology and function of the human liver from the sub-cellular level to the whole organ on the basis of quantitative data.[46] The Human Brain Project has also set itself the goal of developing a computer model of the human brain from microscopic and electro-physiological data within the next ten years.

CONSEQUENCES FOR LABS:

1. Classic wet lab work will be increasingly reduced, the amount of computer work will grow. This will increase the share of work in the office space compared to the wet lab space.[47]

2. In addition to hypothesis-driven research, data-driven research based mainly on data analysis and interpretation is becoming established.

3. As a result of the reduction in wet lab research, savings can be made in both the building and the operation of a research institute. An ever larger share of research can be performed independently of location.

4. Investments in the building, operation and maintenance of server rooms will increase. In addition, the servers will need a great deal of energy to store and process large data volumes.

PARTICIPATIVE SCIENCE

Many developments in the past few years have demonstrated that many members of the public have a strong desire to take a hand in scientific research. Members of the Do-It-Yourself (DIY) biology community, for example, are setting up biotechnology labs for shared used in kitchens, garages and museums around the globe. Professional scientists, amateurs and children alike use them for experiments. Many hope that their movement will have an influence on biotechnology similar to that of the 1960s hacker community on the development of the personal computer.[48] Others want to speed up the transfer of new technologies to emerging economies, or would simply like to bring science closer to people.[49]

Citizen science projects are a more top-down type of citizen participation: the work of the amateur researcher is channelled towards a specific goal and coordinated by a professional scientist. Digitisation has simplified the recruitment and coordination of amateurs to such an extent that citizen science has been experiencing a boom for some years now. The way in which volunteers are involved ranges from online games to microbiology experiments that are conducted in the home. For example, players of the EyeWire computer game reconstruct the neuroplexus of the retina,[50] while the ILIAD project's amateur researchers look for new antibiotic substances.[51]

Another way that citizens can try to influence scientific research is by simply donating data. Platforms of the Quantified Self movement and of patient networks such as PatientsLikeMe have a growing data pool at their disposal that is already being scientifically analysed today.[52] Crowdfunding platforms like Kickstarter and RocketHub, finally, give individuals the opportunity to support citizen science or DIY biology research projects financially.

"EVEN THE NICEST MEETING SPACE IS NO USE IF THE BOSS DOESN'T ENCOURAGE A CULTURE OF EXCHANGE AND COLLABORATION. TOP MANAGEMENT PLAYS A CRUCIAL ROLE IN SHAPING THE TEAM CULTURE AND WORK CULTURE."

Marc Dusseiller

The desire for more consultation and involvement is also accompanied by a demand for more transparency. The latter explains the rise of open access: more and more research institutes are making their scientific findings, ideas, discoveries and methods available to fellow researchers and the public free of charge.[53] The Swiss National Science Foundation, for example, is of the opinion that the results of publicly-funded research should be accessible free of charge.[54] In academia, the universities are pursuing a similar route with their Massive Open Online Courses (MOOC).

CONSEQUENCES FOR LABS:

1.
Lab buildings are opening up to society.
More recent research buildings achieve this with central urban locations, accessibility to the public and infrastructures that can also be used by local people, as well as by exhibiting their latest research findings.

2.
The open access principle is leading to a more diverse, networked scientific community.

4

AREAS FOR ACTION

FROM SOCIAL PARTICIPATION TO THE USE OF TECHNOLOGICAL INNOVATION – IN FUTURE, LABS WILL HAVE TO ACCOMMODATE A VERY WIDE RANGE OF NEEDS.

The above-mentioned developments are changing the framework for laboratories' operation and the demands made on labs. W.I.R.E. has identified six areas for action that should be addressed by means of architectural measures, changes in the scientific culture and resource allocation.

1.

ALLOW DIFFERENT TYPES OF WORK – ENSURE SOCIAL INTERACTION

Biomedical research is moving further and further away from the wet lab and towards office work. The goal here is to use spatial design and organisational measures to support the widest possible variety of work forms – concentration, group discussions, wet lab work, informal discussions etc. [55] In addition, users and their projects change frequently, as do the methods used, processes and the composition of the research groups. The lab has to support this by adapting easily to new requirements. This ranges from mobile infrastructure to the conversion of office, lab or service space into a different space category.[56,57]

Despite the process-based separation and adaptability, interaction among the researchers must be ensured. Even if they do different work, the members of a group should be able to develop a sense of belonging together. This can be accomplished either by throwing the wet lab and the office space into one, or by ensuring visual contact between the two workplaces. This is a central factor for interdisciplinary groups in which the focus of the employees' work differs.[58] Enabling and promoting social interaction is fundamental to ensure that modular, interdisciplinary labs run smoothly.

2.

USE TECHNOLOGY - ALLOW INTUITION

Biomedical research is becoming more technology-intensive. Labs therefore have to be designed both for automated processes and machines and for humans. A core factor is to ensure networking between man and the machine, while at the same time making the human beings the central focus. With the increase in data-driven research and faith in algorithms, it must never be forgotten that human intuition and imagination will remain central pillars of lab research.

3.

FOCUS ON INTER-DISCIPLINARITY – PROMOTE SPECIALISATION

Research requires an interdisciplinary problem-solving approach to deal adequately with the complexity of future challenges. Interdisciplinary research institutes, labs and funding projects have to be encouraged for this purpose. In addition, interdisciplinary forms of cooperation have to be supported architecturally by open lab layouts, shared infrastructure, informal meeting-places and visibility, so that the researchers have a sense of community.[59]

At the same time, top-flight research in the individual disciplines has to be enabled. Even though solving complex problems depends more and more on work among integrated disciplines, practical implementation is often handled by single disciplines. It is important for researchers to be able to depend on obtaining access to the required expertise in their own disciplines when implementing the proposed solutions.

4.

GIVE RESEARCH FREEDOM – ENSURE EFFICIENT EXECUTION

Generally, fast results and a high success rate are demanded of research projects. This rationalisation and supposed efficiency improvement can lead to preference being given to research projects based on incremental progress when funding is at stake. The courage to take more risks on the financial side is crucial so that researchers have the freedom to take new directions, away from scientific compensation mechanisms or profit orientation.[60,61]

This also means projecting this research spirit by building labs with high-quality architecture and optimum spatial and non-research-related features. Alongside freedom of thought, the capacity to put projects into practice and execute them efficiently in a goal-oriented environment must also be ensured.

5.

BUILD INTELLIGENT AND SUSTAINABLE LABS

Social, economic and ecological sustainability and environmentally-aware behaviour are gaining priority in our society. The construction and operation of labs, which consume a multiple of the energy of comparable office buildings, brings the ecological dimension particularly to the fore. Therefore, in addition to structural measures (heat insulation, cooling, photovoltaics etc.), economies are needed in air conditioning and ventilation, which are responsible for a large share of the energy consumption. There is great potential in this area thanks to miniaturisation and robotisation.

However, the integration of labs into public space is also important here. Energy efficiency measures such as solar panels can impair the aesthetics of public areas. The well-being of employees also has to be taken into account, for example in minergy standard buildings. However, in the final analysis sustainability measures often involve costs, which e.g. start-ups and bottom-up initiatives find harder to cope with than multi-national corporations do. Sustainability targets should not be allowed to hamper the spirit of innovation.

6.

OPEN SCIENCE UP TO SOCIETY AND GET IT INVOLVED

The population at large often remains unware of the value of biomedical research because the results are abstract and their conversion into practical applications takes a long time. The scientific community has to find ways to actively promote debate on its results in the social context and to make them easy to understand. If scientists were to withdraw from public opinion-forming, it would have a negative impact on their acceptance and their integration as part of the general population.[62]

However, researchers do have to be protected from the public's values and expectations so that they can concentrate on their core business. Freedom of thought should be enabled and and the benefits to society as a whole highlighted simultaneously. For controversial fields of research in particular (e.g. stem cell research, genetically modified organisms), it is important to design the research framework in such a way that the research is not impeded by an unclear legal situation or the public's unilateral right to interpret the issues.

5

THREE SCENARIOS

THE LAB OF THE FUTURE WILL BE EASIER TO ADAPT TO A WIDE RANGE OF NEEDS, WILL FURTHER ENCOURAGE DECENTRALISATION AND THEREFORE COMPREHEND AND SUPPORT HUMANS BETTER IN THEIR DIVERSITY.

Building on the previous chapters, W.I.R.E. has outlined three scenarios dealing with different aspects of the three dimensions. Common to all the scenarios is an outlook for the medium-term future which, however, is not detached from today's framework for operation.

The three dimensions of space, culture and resources are used again in developing the scenarios. FIG. 3 illustrates schematically the spectra within which the future changes could develop.

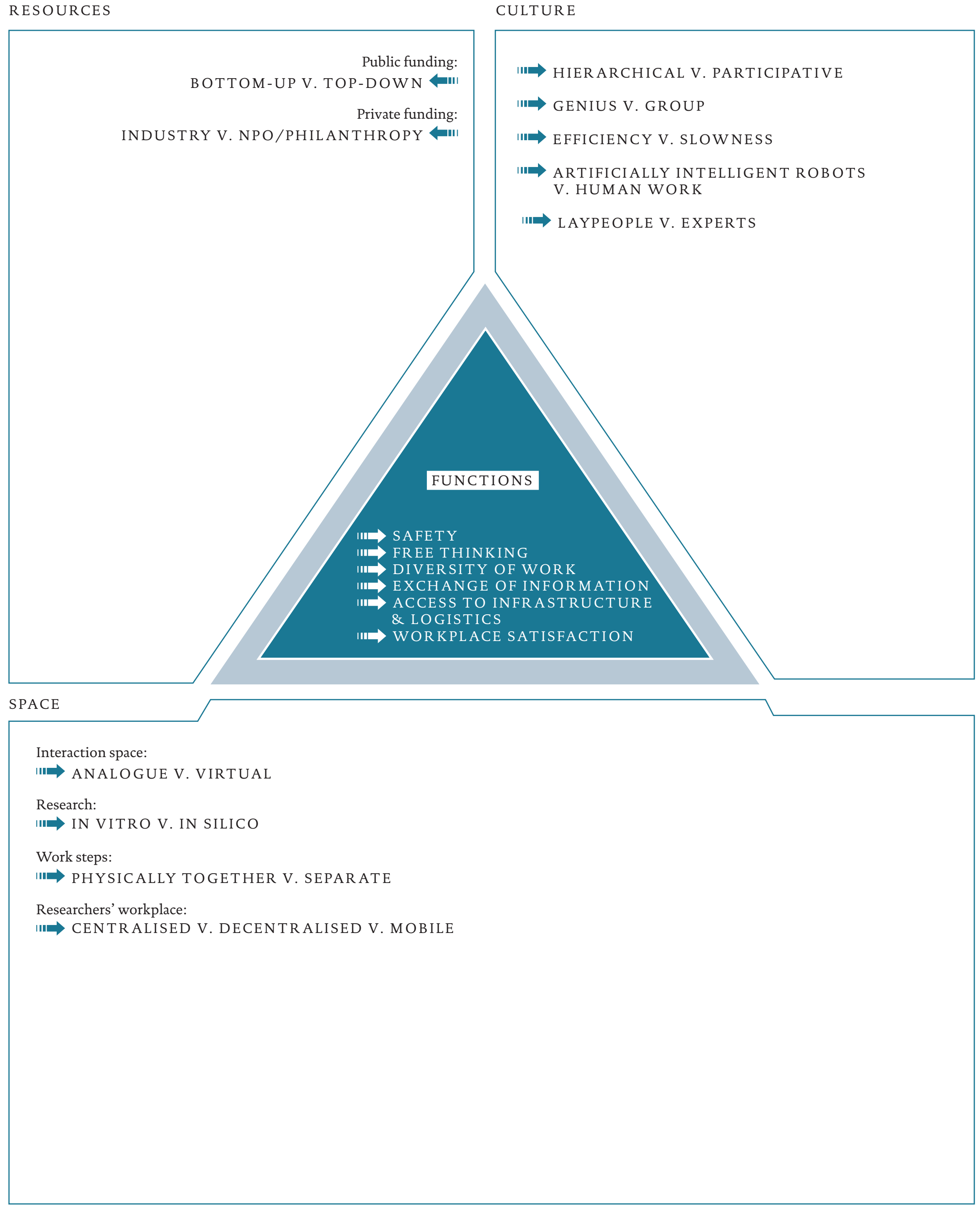
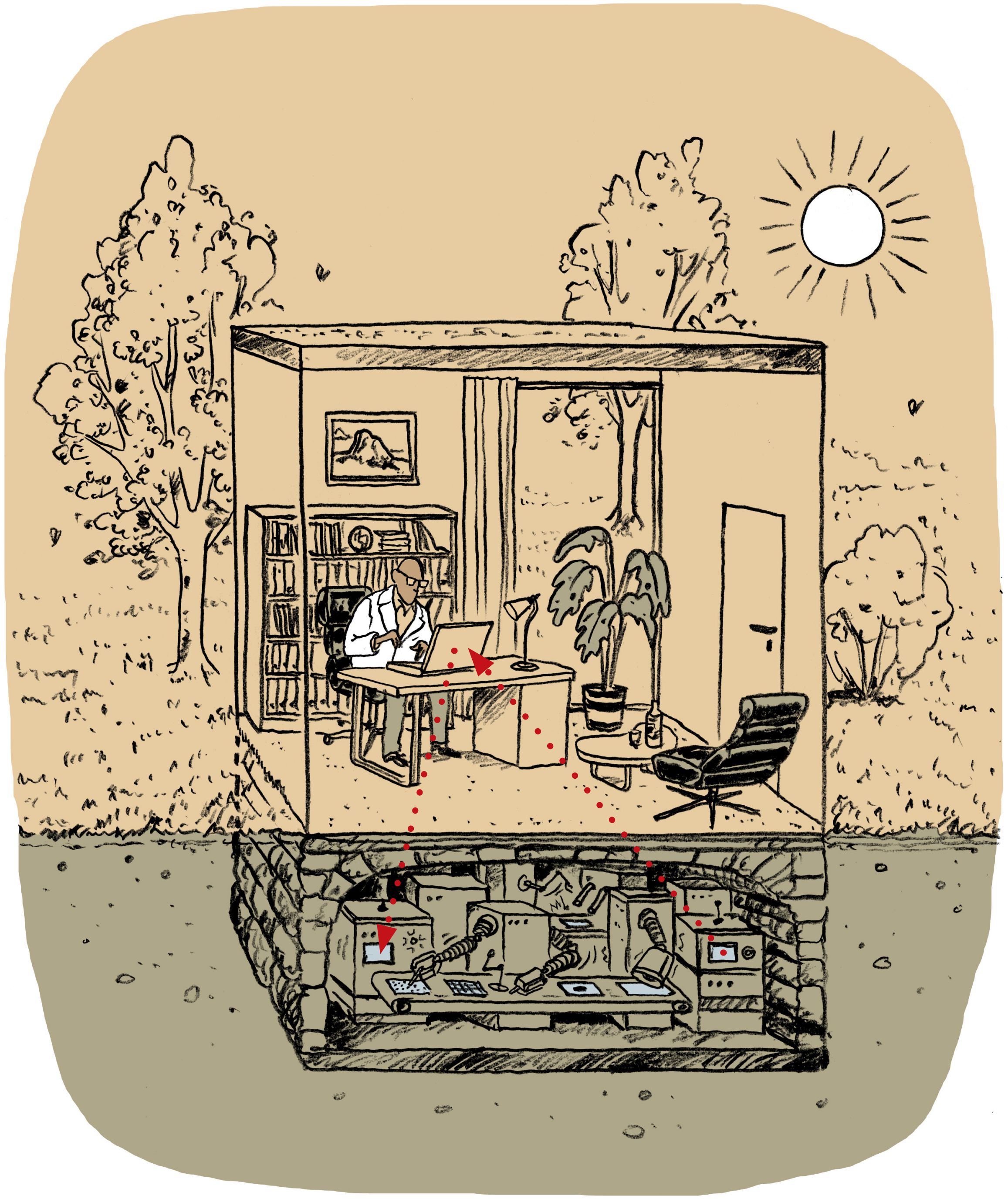


FIG. 3 :
Model of the three dimensions of the lab of the future
Source: W.I.R.E., own design



SCENARIO 1

THE AUTOMATION OF LAB WORK

While industry focuses on research into big-selling, lucrative areas, government pursues the non-commercial research. It takes care of the preservation and development of public health and carries out research in areas that don't make commercial sense for industry, e.g. the development of drugs to combat rare diseases. Both industry and government place research contracts with central research organisations (CROs), where the work is shared by humans and robots. The responsibility for the creative work process of research, for example creating hypotheses, lies with the humans. Robots carry out the experimental work: they organise experimental setups, program the appropriate algorithms and carry out experiments both in vivo and in silico. The robots' findings are continuously passed on to the researchers and are incorporated directly into the design of subsequent experiments.

PRACTICAL RELEVANCE:

New professions are developing in research which need a response in the form of new training concepts and contents. At the same time, there is a risk that humans will lose their connection with research and the factor of random chance will be minimised by the automatic execution of the experiments. At the same time, basic research could be neglected for applied research.

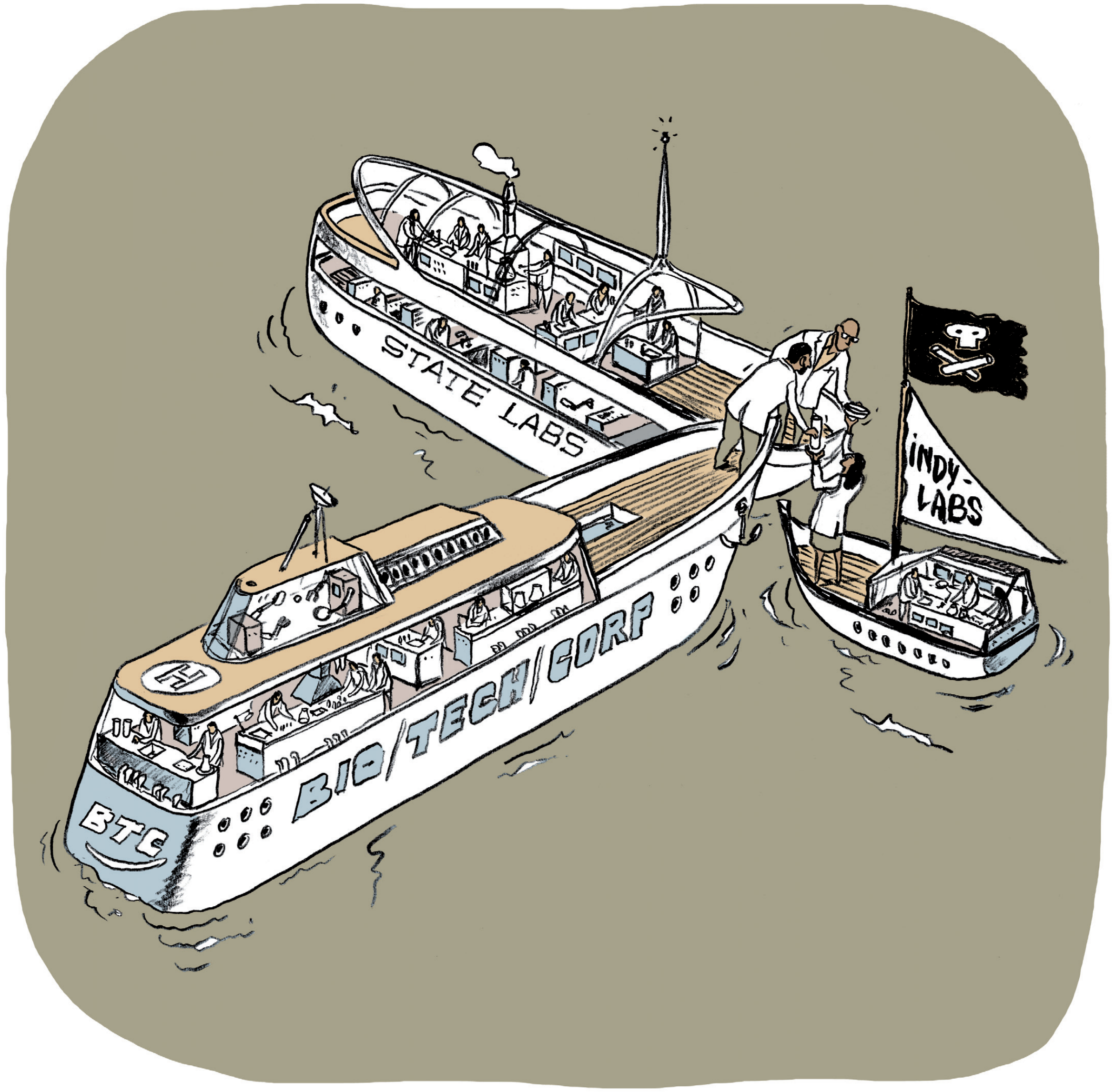
SCENARIO 2

THE DECENTRALISED AND MOBILE LAB

Researchers at large multinational corporations are spread across the entire world and mostly work from home. They simulate their experiments in silico or conduct them in vitro. The in vitro experiments are done on chips in miniaturised form. To protect the environment and control environmental conditions better, researchers have a self-erecting tent at their disposal in which they conduct their experiments. When the tent is down it is compact and can be transported easily in a suitcase. It allows researchers to conduct wet lab work even when travelling, they carry the required utensils with them. The results of the simulations and experiments are stored in Clouds so that they can be shared with the research community all over the world. When the researchers want to talk to colleagues they use spectacles that allow them to communicate virtually. Face to face contacts are becoming rarer, travel is decreasing, at the same time networking can be carried out faster.

PRACTICAL RELEVANCE:

The distinction between work and leisure time is becoming more and more fuzzy, including in scientific research. Working at home is becoming the norm, it is difficult to maintain the dividing line between work and play. Companies and institutions are reacting to this with small, modular and adaptable buildings in which researchers meet in a given required constellation. However, this goes hand in hand with a culture shift that depends on trusting instead of controlling employees. The home office is becoming increasingly important, a development which is reinforced by the demands of the millennials, who are used to working in a non-location-specific and independent manner.



SCENARIO 3

THE MODULAR & CROSS-SECTOR INTEGRATED LAB

Research institutes are organised like ocean-going fleets. The ships are the researcher's workplace and home. Certain ships are paid for by government research funds, others are financed by industry, and others again have amateur researchers working on them who raise their financial resources by crowd-funding. The ships can be put together to form conglomerates in order to adapt the combinations of researchers to the problem to be solved.

These research ship conglomerates are mobile, move back and forth among the continents and lay anchor temporarily at the location where the best science and industry partners to solve the problem are based. Regulatory provisions can be avoided, and at the same time regional and local problems are resolved locally, where appropriate involving locally based researchers who are most familiar with the disease in question.

PRACTICAL RELEVANCE:

Even today, multinational companies are moving their research units to the most attractive locations for the relevant research fields in terms of operating frameworks and regulatory conditions. Although this creates new jobs in the short term (mostly) in emerging economies, it also bears the risk that companies will lose their attachment to their original home countries. Interaction with the local population becomes more difficult and multinational companies are very much perceived as aiming for profit maximisation.

6

CONCLUSION AND OUTLOOK

The goal of the Lab of the Future project and the resulting brief study was to perform an audit of the current and future framework of operation and, building on that, to define areas for action and develop visions. Using the model of a lab developed by W.I.R.E., it proved possible to define the most important dimensions and functions of a laboratory, including the ways in which they will change in the future. It was found that the core conflicts in future lab architecture do not revolve solely around the spatial level, but are also influenced by the prevailing research culture and available resources.

The results of this brief study, which highlights the long-term changes in the technical, social and economic framework in which laboratories operate, indicate that responses to changing human needs will be required in the future. This means that a debate has to be conducted about the status of research in society and how it should be funded, and also that labs have to be opened up to the public in the physical, spatial sense in order to encourage this debate. The lab as a centre of knowledge creation performs one of the core functions of social, scientific and economic progress, i.e. fostering and enabling innovation and invention. Lab work thus becomes a metaphor for knowledge work in general – which explains the relevance of analysing the lab design of the future.

For this reason, it is important to consider the results of sub-project I – the areas for action in conjunction with the scenarios – in more depth in a second step, and to develop them further towards practical implementation. The goal of sub-project II will be to develop and implement prototypes for a Lab of the Future together with science and industry. Basic requirements for this purpose will be defined and an ideas competition set up to invite various teams to meet this challenge: in this study, too, the insights gained from the existing project will produce new issues.

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DR STEPHAN SIGRIST is the founder and head of the W.I.R.E. think tank. He has spent many years engaged with developments in the life sciences and with long-term trends in business and society. After studying biochemistry at the ETH Zurich, he worked in medical research with F. Hoffmann-La Roche AG, as a management consultant with Roland Berger and as a Senior Researcher with the Gottlieb Duttweiler Institute. Stephan Sigrist has authored a large number of books and publications, advises companies and political institutions on strategic issues and is a frequent speaker at international conferences.

DR NICHOLAS BORNSTEIN is a Senior Project Manager with W.I.R.E. In this role he is responsible for collaborations and external projects with partners from science, business and politics. He previously worked for the Swiss Federal Department of Foreign Affairs (FDFA) in Brussels as a diplomat with Switzerland's mission to the EU and prior to that in the international division of the Federal Office of Public Health, where he was deeply involved in analysing developments in healthcare in the European context.

DR JULIA STRICKER was a former researcher with W.I.R.E. and in this role was responsible, together with the project management, for the content and organisation of the work on the brief study on the future of the scientific lab. Prior to working with W.I.R.E., she studied medicine at the University of Zurich and worked as a resident physician in the Department of Neurology at the University Hospital Zurich.

GERD VOITH is the founder and Chairman of SAVIDA AG, which is based in Basel and has offices in Shanghai and Miami. The focus of SAVIDA AG is on consultancy and technical expertise for building services, lab design, energy concepts and sustainability in the area of life sciences and green building projects. In his role as consultant, Gerd Voith covers all areas from initiation and project development to support and training. His aim is to find innovative solutions and support his partners in realising projects through to implementation. Due to his global lecturing activities, Gerd Voith has been offered a professorship at the University of Hong Kong.

MATTHIAS GNEHM has won international acclaim with his comics and graphic novels. He was born in Zurich in 1970 and completed studies in architecture at the ETH Zurich. Matthias Gnehm now works as a freelance comic artist and lives with his family in Zurich. In 2008 he was awarded the "Werkjahr", a one-year bursary, of the City of Zurich.

W.I.R.E. is an independent Swiss think tank which engages with global developments in business, science and society. The focus of its work is to critically examine established points of view, make ongoing trends transparent and develop new concepts and ideas for the future. Adopting an interdisciplinary view of research, W.I.R.E. acts as a laboratory for interaction between scientists and practitioners and as a platform where players from different fields of activity and knowledge can network. W.I.R.E. boasts an international Board of experts, thought leaders and decision makers.

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2nd edition

Authors: Stephan Sigrist, Julia Stricker, Nicholas Bornstein, Gerd Voith
Illustration: Matthias Gnehm, www.matthiasgnehm.ch
Layout: Kristina Milkovic
Translation: Helen Robertson
www.thewire.ch

For reasons of linguistic simplicity we usually use the masculine form in this publication.
This form always also includes females. It should be noted that grammatical gender is not identical with biological sex.

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NOTES

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