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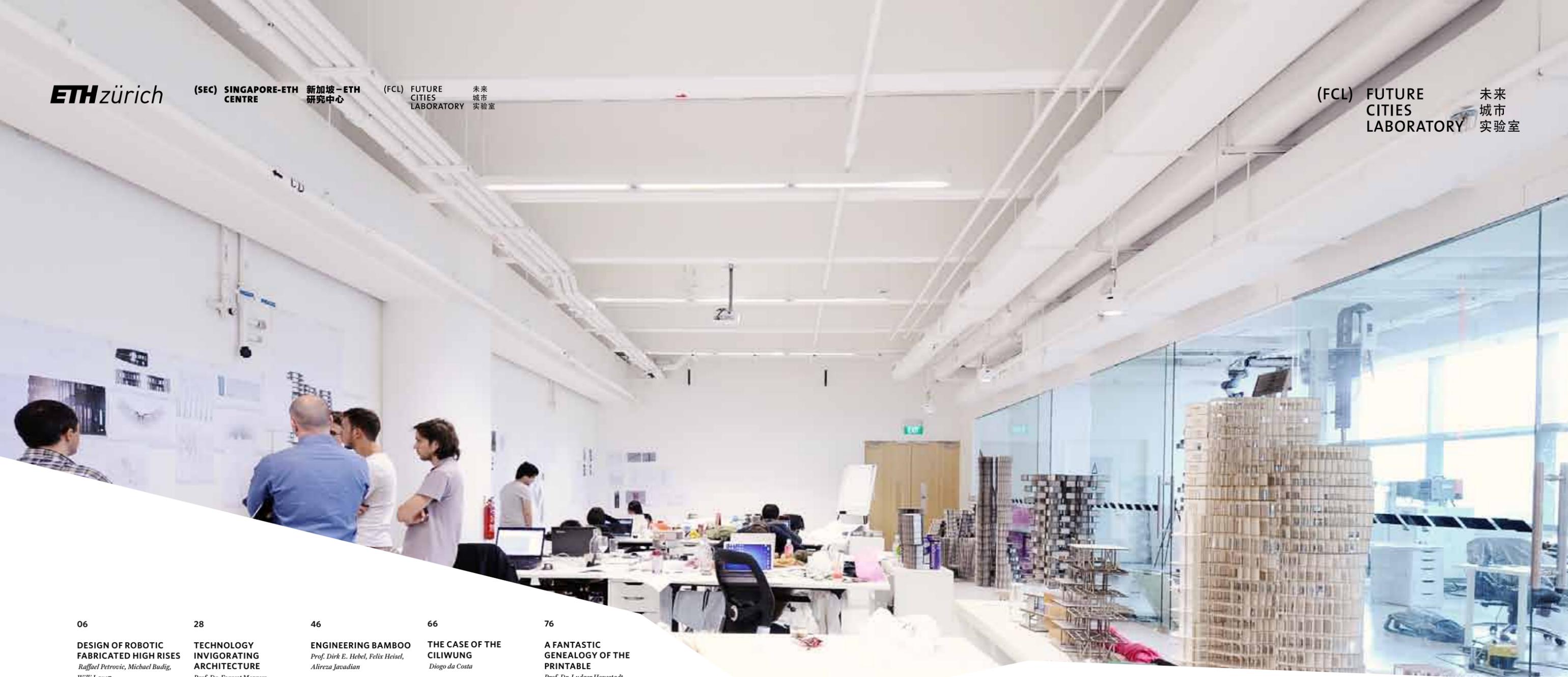
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TECHNOLOGY

Future Cities Laboratory

The Future Cities Laboratory (FCL) is a transdisciplinary research centre focused on urban sustainability in a global frame. It is the first research programme of the Singapore-ETH Centre for Global Environmental Sustainability (SEC) and home to a community of over 100 PhD, Postdoctoral and Professorial researchers working on diverse themes related to future cities and environmental sustainability.

Cities accommodate more people today than at any point in history. Cities are more interconnected than ever before. Cities concentrate some of the most intractable of contemporary social, political and economic dilemmas. And, as substantial consumers of energy and producers of greenhouse gases, cities are central to the project for global environmental sustainability. But successful cities are also, more than ever, the engines of national and transnational economies, sites of diversity and creativity, and centres of innovation and entrepreneurship. As such, cities are likely to be the places where the challenges of urbanisation and environmental sustainability will be most productively addressed.

Editorial

The Future Cities Laboratory (FCL) is home to a heterogeneous community of researchers that thinks about the complexity of cities and actively engages in their development in the long term through research, planning and design. It is the first such program of the Singapore-ETH Centre for Global Environmental Sustainability (SEC), and is located in a tower building in the University Town campus at the National University of Singapore. FCL takes its role as a laboratory seriously, nurturing the cultures and practices of interdisciplinary, scientific experiment.

The FCL Magazine is a periodical about research. It does not aim to present unquestionable research results, nor fully worked out 'solutions' to the myriad dilemmas that contemporary and future cities unfold. Rather, it aims to show things which are not yet fully resolved, work in progress, approaches to longer term issues. In so doing, the magazine will embrace mistakes and failures. It will celebrate questions, highlight methodologies, and revel in the shaping of research.

FCL Magazine is time limited. It will only be alive, as long as the Future Cities Laboratory is active. It draws its content and energy from the researchers inside FCL. It has a dual audience: those researchers within FCL, for whom the magazine is intended as a provocation for discussion and prompt for critical reflection on interdisciplinary approaches to the city; and colleagues who work in related fields, for whom the magazine is intended as a source of information on the work being conducted at FCL, and as an invitation to engage.

The first issue of the FCL Magazine aims to address the role of technology in FCL's research activities. The word technology is derived from the Greek words *techné*, meaning art or craft, and *logos*, meaning word, intellectual capability, doctrine, rational or even reflection. Technology therefore suggests a mentality of "thinking" on what we are "doing". For a laboratory setting, this seems to be an ideal point of departure and is more open than simplified definitions such as technique or machine.

Over the past two and a half years various ways of using technology in FCL's daily work have emerged in our research community. While some claim, that architects in general show a fear of implementing technology in their designs, others try to define the term in an alternative approach by developing links between local traditions and state of the art technologies. Others are impatient to see new developments in the technological sector and claim that information technology is printing technology. Robotic drones create artificial three-dimensional maps of our immediate environment and reduce it to a thin layer of data carpets and point clouds.

Technology is conventionally described in low-tech and high-tech variants. This first issue of FCL Magazine offers a platform for divergent definitions of technology, and offers suggestions, clues, and approaches on how to operate on a shifting. It gives a selected overview, no more and no less.

Dirk E. Hebel and Stephen Cairns, Singapore, September 2013

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Design of Robotic Fabricated High Rises

Raffael Petrovic, Michael Budig,
Willi Lauer

Co-Authors: Fabio Gramazio,
Matthias Kohler, Silke Langenberg

FCL Research Module:
Digital Fabrication

Robotic fabrication has the potential for variety and differentiated assembly – if not just used for the execution of purely repetitive mass fabrication processes. Most attempts at using robotic processes in architecture still remain exceptions, prototypes or even failures at a larger scale, as their approach is either to automate existing manual processes or to automate the complete construction process. This paper shows an on-going investigation into the potential impact of robotic processes on the design and construction of large-scale building structures.

The high rise test bed

High rises represent the most common typology for residential projects in Southeast Asia, where they dominate large parts of the urban landscape. A continual demand for housing space coupled with decreasing availability of useable land resources led to the development of mono-functional and highly repetitive urban environments (Fig. 01). The strict separation of functions together with construction technologies, driven by efficiency and economic factors, represent a quite anachronistic industrial paradigm. Hence the questions arise, how contemporary computer aided architectural design could contribute to the differentiation of these environments, and how the investigation of robotic construction could support this agenda in the context of large buildings?

The research on Robotic Fabricated High Rises is conducted in the framework of a Design Research Studio for Master students from ETH Zürich and the National University of Singapore at the Future Cities Laboratory in Singapore. Their projects investigate the potential impact of robotic fabrication on the built environment, by creating robotically constructed 1:50 models of high rises. In parallel a team of PhD researchers



Fig. 01 Public housing development in Punggol, northern Singapore

addresses robotic construction in a 1:1 scale, focussing on computational design and material systems. The Studio and the PhD researchers are in constant exchange, influencing each other and forming an interdisciplinary robotic test laboratory.

Since the advent of computer aided design (CAD) in architecture in the 1980s, architectural design migrated from the physical space of model building to the virtual realm of three dimensional modelling. Consequently, the digital design was detached from the physical reality of construction and its materialisation pushed to the end of the design process instead of being in constant negotiation with it. Rapid prototyping technologies – like three dimensional printing – amplified this separation by allowing the production of architectural models as whole solid objects, without defining or visualising their construction

The use of industrial robots allows overcoming the separation of the virtual and the actual. Robots are generic machines¹ that have the ability to move and orient precisely in space according to simple commands. These commands can be generated by algorithms. Within the Design Research Studio each student group is asked to develop a specific computational design and a unique strategy for its robotic fabrication process. The physical and the virtual are in constant negotiation with one another, therefore constraints of the model, for example in terms of structural stability or minimum element sizes, directly influence the computational design setup in a constant feedback loop. The model scale of 1:50 allows for a certain abstractness of the design's tectonics. The sheer size of up to

four metre high models requires the students to tackle problems of structural stability and construction logic from the very beginning on.

The robotic laboratory

For the production of models in 1:50 scale and investigations in larger scales three robotic facilities were installed at the Design Research Studio in Singapore, each one consisting of an industrial robotic arm (Universal Robot, UR) mounted on a linear two axis system (Fig. 02). Thus the robots' workspace could be increased from a diameter of roughly one meter to a construction envelope of 3.8 metres height. A laser cutter amends the setup, allowing prefabricating elements for the construction of the models and producing tools to extend and customise the robotic setup.

Usually industrial robots are installed in glass enclosures or in separate rooms for safety reasons. The UR robots are small enough to be suited for human-machine interactions, which are essential for creating a feedback loop between computational design and robotic fabrication, and thus increasing iteration cycles of building models. The interface between the robotic arm and the actual building components is completely open for adaptation to different materials and geometries. All grippers are custom designed.

The robots are controlled by using *Your*, a *Python*² library and *Grasshopper*³ component collection (Lim, Gramazio and Kohler, 2013). This open setup allows exploring a wide range of fabrication processes, from simple picking and placing of elements, to complex material deformations.

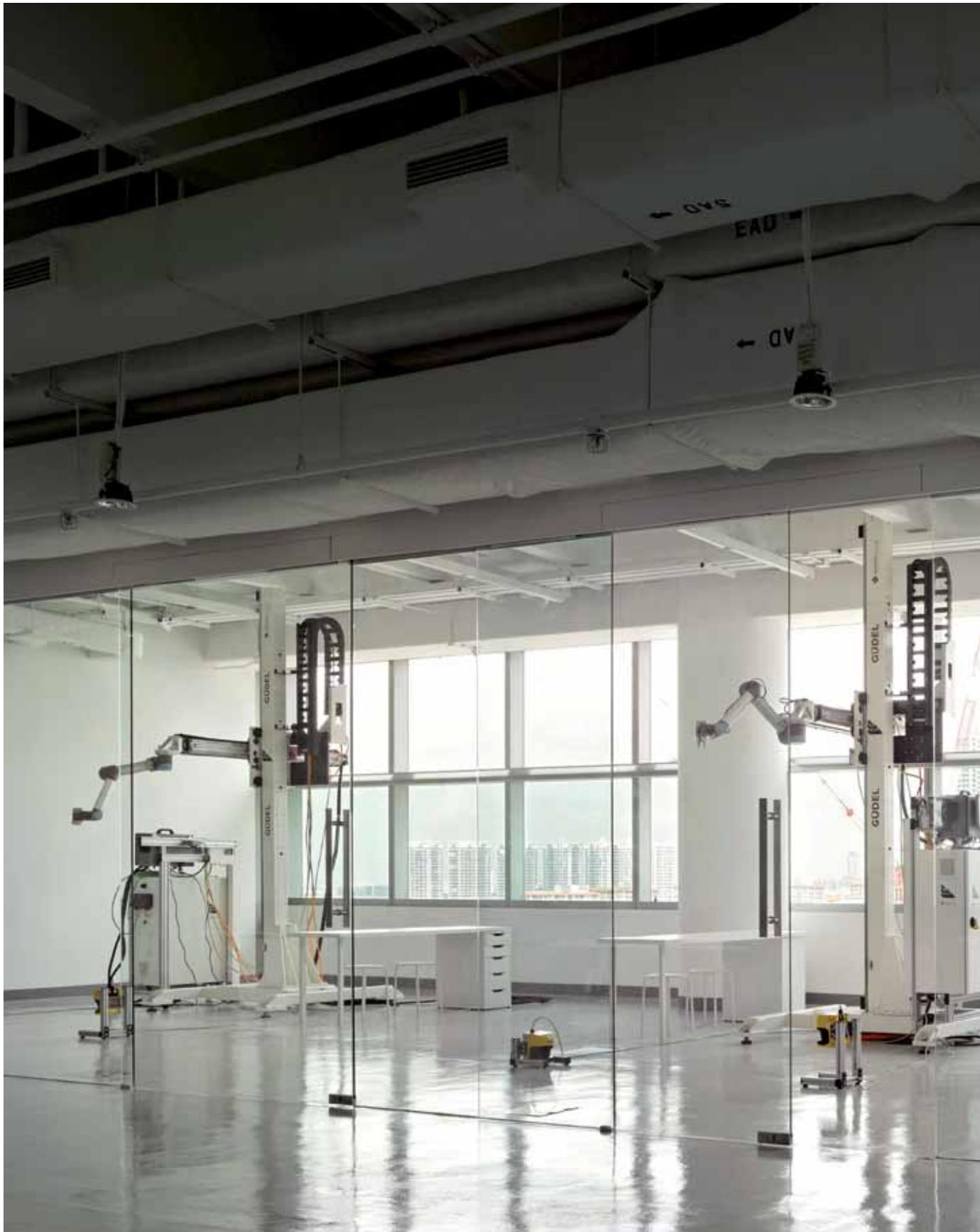


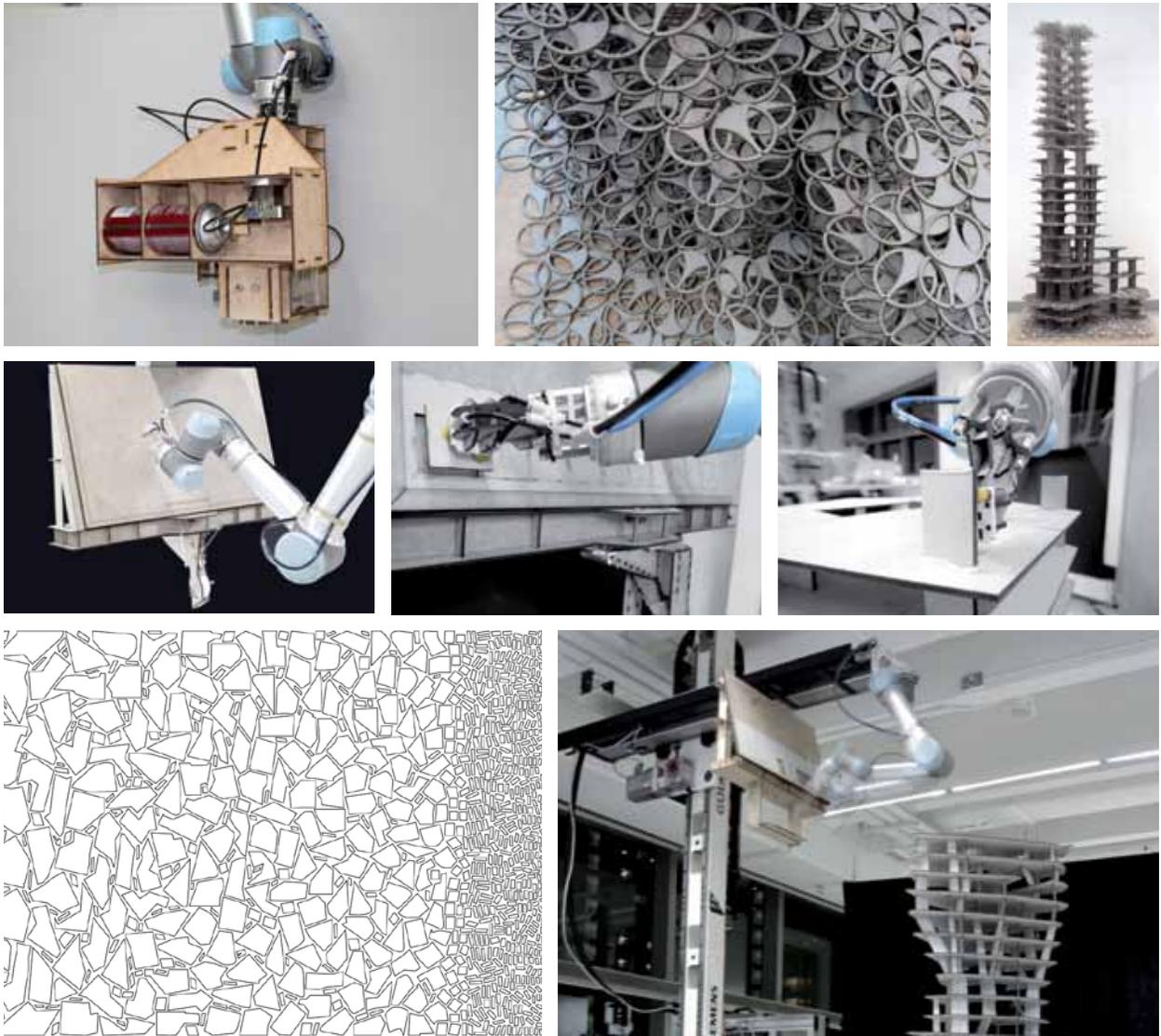
Fig. 02 Robotic facilities at FCL Singapore





Fig. 03 Vacuum gripper for picking and placing of flat cardboard elements, mounted on the UR robotic arm





04	
05	
06	07

Fig. 04 Design Research Studio 2012 - Phase 1. Gripper design (left). Standardised component assembled with different position and orientation (centre). Final tower (right). Students: Kramer, Stünzi, Valcarce, Waldburger

Fig. 05 Design Research Studio 2012 - Phase 1. Plywood feeder for picking from laser cut sheets (left). Robot picking an element from a sheet (centre). Robot placing a wall on the model (right). Students: Genhart, Goldener, Thonney, Wullschlegler

Fig. 06 The final tower consisted of 910 geometrically unique pieces (left). The final tower during robotic fabrication (right). Design Research Studio 2012 - Phase 1, Students: Genhart, Goldener, Thonney, Wullschlegler

Fig. 07 The final tower during robotic fabrication (top). Robotic bending of aluminium sheets (bottom). Design Research Studio 2012 - Phase 1, Students: Ernst, Strohbach, Rickhoff, Tessarz

Differentiation of tower designs

The first aim of the Design Research Studio was to build models as high as possible to gauge the limits of the robotic facilities. Initial towers have been simple stacked configurations, for which the students developed different vacuum gripper systems to glue and place cardboard elements (Fig. 03). Thereby material thicknesses, drying times and height deviations caused by the applied layers of glue had to be considered. The major challenge was to master the negotiation of a computer generated three dimensional model in a physical reality. The first tower studies, just consisting of simple walls and slabs, reflect the learning process. After this initial phase different strategies to utilise the robots' potential emerged.

One group investigated into increasing the resolution of their towers, which consist of up to 15.000 identical cardboard elements. They developed a feeder system with an integrated spray glue can (Fig. 04). This device could hold several hundred pieces at a time and consequently speed up the construction process by minimising the distance the robotic arm had to travel for picking each piece.

Another group focussed on the smooth integration of the laser cutter, which allows the production of elements with different sizes and geometries. Since the picking point is different for each piece, it is impossible for the robot to pick from a stack. Hence first of all the pieces need to be aligned in a precise way in order to correlate to the digital model, secondly the sequencing of the elements is normally a very time consuming task.

To achieve a more efficient work flow, a corresponding feeder system and *Grasshopper* setup were developed (Fig. 05). The students first constrained the cardboard sheet size for the prefabrication of elements to fit into the robot's workspace. The layouts for these sheets were automatically generated in the digital model and the data was used to cut the cardboard. The individual sheets were then placed directly on the feeder that contained a gluing station. Since the laser cut sheets were generated by code, the data could easily be used to coordinate the picking, gluing and placing movements of the robot. This process radically extended the project's design space (Fig. 06).

A third group saw the potential of the robot in uniquely informing identical parts and developed a *Grasshopper* setup to bend identical sheets of cardboard at various angles. As cardboard quickly proved to offer too little control for bending, the group switched to aluminium sheets. These could be bent precisely to defined angles and allowed for the production of large numbers of uniquely folded configurations out of the same generic element. By bending each piece in two opposite directions each wall was made stable in itself. Afterwards these walls could be arranged into different configuration, in a way that they always intersect with a wall on the storey beneath, to ensure continuous vertical load transfers (Fig. 07).

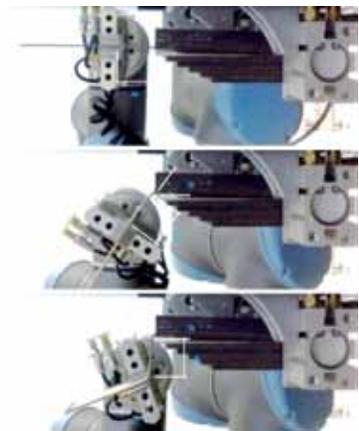




Fig. 08 The bending setup (above). The acrylic stripes are fixed in a linear rail and pulled forward to their designated bending position (middle). The material gets heated up to 550°C for 10 seconds. The robotic arm can now bend the material to any angle between 0° and approximately 160° (at the bottom). After the deformation the material gets cooled down by air pressure. See Fig. 09, left image for the final tower. Design Research Studio 2012 – Phase 2, Students: Kramer, Stünzi

Increasing the complexity

After developing different concepts for more differentiated tower designs, the complexity of the material systems was tried to be increased – which also resulted in an increased complexity of the computational setup, as not only picking and placing locations had to be controlled, but a whole new set of parameters related to material properties were implemented.

As the deformation of pieces during assembly has promised to be a powerful strategy for utilising the full potential of the robotic arm, two student groups decided to deform plastic material by integrating a heat gun in their setups. It allowed them to locally heat up the material and then bend it by using the robotic arm (Fig. 08). As simple heating was not sufficient, the pieces had to be cooled as well in order to avoid retraction and increase assembly speed.

The group bent acrylic stripes at multiple points to create their tower's primary structural system (Fig. 09, left). Another group used the same process to twist acrylic sheets and produce a façade louver system for optimal sun shading (Fig. 09, right).

An entirely different approach to deform material was chosen by the third group, which decided to staple paper stripes by the robot. This process was especially intricate to realise and required the development of a gripper that could pinch two stripes of paper and then staple them together at a specific position. By sliding only one of the two paper stripes backward and stapling it again, it was possible to produce stripes with undulating outlines. These stripes were connected at their beginning and end, producing closed shapes (Fig. 10).

These undulating geometries were used to produce the façades, and exterior, public circulation corridors of a tower (Fig. 11 and 12). Instead of pre-computing the shape of the outline, the group used the material's intrinsic properties. The robot's ability to precisely staple a lot of connections in varying distances thus created a synergy with the inherent ability of the material to produce complex geometric shapes.



Fig. 09: Final tower with its student team. Design Research Studio 2012 - Phase 2, Kramer, Stünzi (left). Final tower close-up of façade louver system, Design Research Studio 2012 - Phase 2, Genhart, Wullschleger (right)

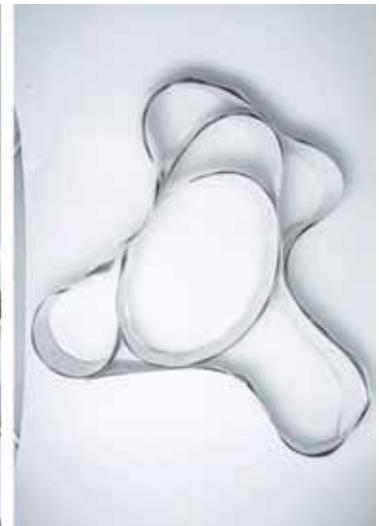


Fig. 10: Robotic stapling process (left and centre). Initial study model of robotically produced geometries (right). Design Research Studio 2012 - Phase 2, Ernst, Rickhoff, Strohbach



Fig. 11 Final model. Design Research Studio 2012 – Phase 2, Ernst, Rickhoff, Strohbach



Fig. 12 Final model, close-up. Design Research Studio 2012 - Phase 2, Ernst, Rickhoff, Strohbach



Fig. 13 Series of 1:50 models of high rises in the studio context, Design Research Studio 2012



Conclusions from 1:50...

The most promising strategy to maximise the robot's potential was to inform the material itself. This process allowed for high fabrication speed, because it could create a variety of geometries out of identical or at least similar elements. Logistic problems inherent in using the laser cutter in combination with the robot were eliminated. In contrast with simple picking and placing, the robot is playing an active role in the form giving process.

The students first tested all processes by hand and explored their potential in simple working models. This practical knowledge was then translated into a computational model, which was further used to explore the design space of their initial idea. The robotic fabrication process seemed limiting and decelerating at first, yet intensified critical reflection during the making and thus improved and radicalised the design later on.

The possibility to build working models automatically reached a complexity that could not be achieved manually and leads to a more direct and sensual understanding of the architectural and tectonic qualities of the individual projects. At the same time, this rigorous link between design and production data obliges the designers to deeply and creatively engage with the fabrication logic, which becomes a part of the design itself. This was exemplified by the diversity of the produced towers (Fig. 13).

... for 1:1 constructions?

The potentials of robotic fabrication in a 1:1 building process is researched in parallel to the Design Research Studio. Even if the described 1:50 processes cannot be directly applied in a real scenario, they offer valuable insights in limits and challenges, structural behaviour or sequencing, and hint towards a possible change of an architect's working mode. In order to use robots on a building site different aspects have to be taken into consideration, some of which were not discussed in the 1:50 model building process: these concern the payload of the robot, the size of the building elements to handle for assembly by the robot, the mobility and cooperation of robots, material behaviour, proper connection details and construction processes. More specific processes and material systems have to be developed – and are already under development within this FCL project.

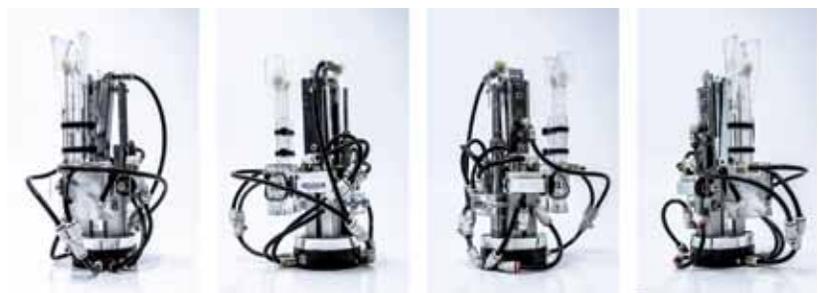


Fig. 14 Gripper for robotic stapling process – Phase 2, Students: Ernst, Strohbach, Rickhoff

On the Use of Slots and Shafts

Informal Cooling Strategies as Indicators for New Cooling Concepts - Microclimate Ethnography in the Ard el Lewa Informal Quarter of Cairo (Egypt)

Dr. Sascha Roesler
FCL Research Module:
Territorial Organisation

Although the significance of vernacular cooling strategies is well accepted among scholars of architecture (Taut, 1937; Fitch / Branch, 1960; Fathy, 1986), the differences between passively cooling a small village house, and cooling a large-scale city building have to be considered carefully. But what about the large-scale high-rise informal buildings in a big city like Cairo, Egypt (Fig. 02)? Have these buildings something to teach us in terms of cooling large-scale mass housing developments (Fig. 01)? In this article I'm going to argue that the very young phenomena of informal building is the missing link between vernacular and academic construction. The gap between tradition and modernity can be bridged by investigating informal cooling strategies. During fieldwork conducted in an informal quarter in Cairo (Egypt, 2010) I had the opportunity to live with and to investigate such informal cooling strategies.



Fig. 01 Construction site, Ard el Lewa (Cairo, 2010)

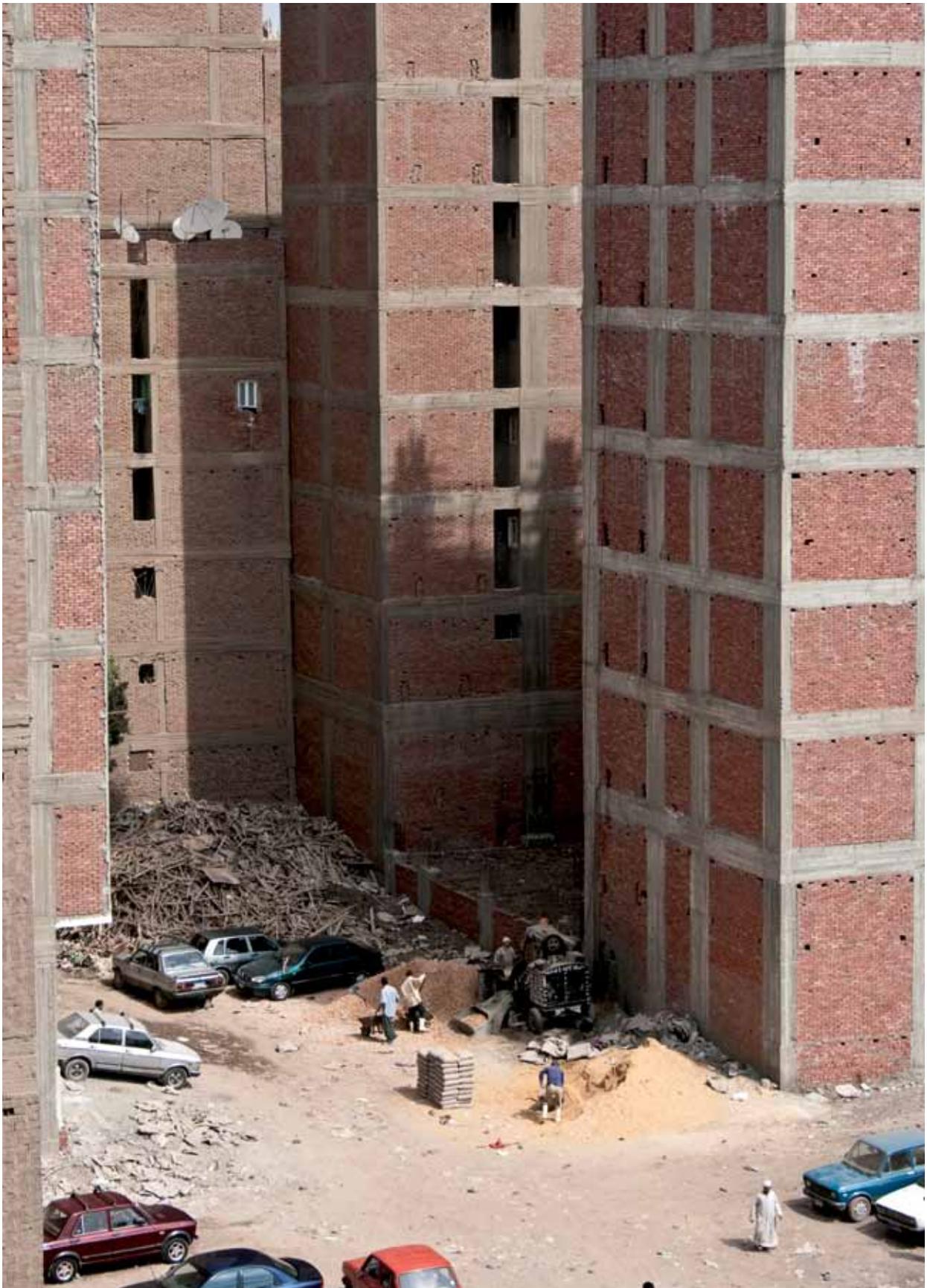


Fig. 02 Informal high-rise buildings in the Ard el Lewa quarter (Cairo, 2010)

Rethinking low-tech strategies in architecture

At present, in many parts of the world, a fundamental transformation of traditional building methods is occurring. In Indonesia, for example, there is a trend away from filigree construction (wood and bamboo) towards solid construction (fired bricks and concrete). In Egypt, the trend is in the opposite direction, but has similar results: traditional thick-walled solid construction methods (mud bricks) are being abandoned in favour of more filigree structures (fired bricks and concrete). The climatic implications of these developments are indeed dramatic: the microclimate-regulating capacities of traditional building structures are increasingly replaced by new technologies, including air conditioning. The response to climatic conditions becomes a technical or scientific problem for architects and engineers without any cultural and social implications, divorced from the everyday practices of a building's inhabitants. Natural energy resources such as wind and solar are replaced by fossil fuels and electric energy.

Today, there is a need to rethink those architectural concepts which help to reduce (1) the mere technological impact on building methods, and which strengthen (2) the structure itself as a multidimensional means to maintain and enhance the climatic comfort of the users. Structures not only bear (Fig. 03). Instead of searching for low tech solutions, architects should first carefully re-evaluate the *everyday practices* that make an architectural solution appropriate for its users. In his book *Small is Beautiful*, (Schumacher, 1973) the economist Ernst Friedrich Schumacher explained the term 'low-tech' very precisely: Low-tech means to involve people into the production, the operation and the use of things. The so-called *intermediate or appropriate technologies* gained their full importance, mainly in the global south, as a labour-intensive alternative to the capital and energy-intensive technologies of the industrialized countries. In other words, architects need to integrate both *technology and everyday practices* into their considerations.

Climate responsive design research is a good example of how appropriate technologies are reliant on both technological and ethnographic insights. The "affinities" (Marcus, 2010) between climate research and ethnographic fieldwork have been apparent for decades, since architects first used the thermodynamic knowledge of building physics in order to better understand vernacular building phenomena (Roesler, 2013). One might speak of a "climate ethnography" (Crate, 2011) conducted by architects. In his book *Natural Energy and Vernacular Architecture* (1986), Hassan Fathy describes two ways of influencing air movement both inside and outside the traditional Arab house: "The architectural design can ensure such natural air movement through two principles. In the first, differences in wind velocity produce a pressure differential which results in air flowing from the higher to the lower air pressure region. In the second, air is warmed, causing convection, with the warm air rising and being replaced by cooler air" (Fathy, 1986).



Fig. 03 Building with the two basic types of clearance: a shaft within the building and some slots along two facades

Natural Ventilation in Ard el Lewa

According to estimates, 65% of Cairo's inhabitants are living in informal and semi-informal settlements today. Apparently, the vast majority of these buildings are not regulated by any kind of air conditioning devices, added before or after completion of the buildings. The climate of Cairo is a hot desert climate with summer temperatures of around 35 °C. Considering the climatic conditions of Cairo, there is a obvious need to attenuate these conditions architecturally with appropriate building methods and typologies and using traditional cooling strategies, as this fieldwork revealed. Very old mechanisms for controlling a building's temperature and enhancing the comfort of inhabitants are still in use today. I spent one month in the informal quarter *Ard el Lewa*, which lies in the west of the city of Cairo, at the edge of the formal quarter *Mohandessin*. Since the 1970s, *Ard el Lewa* has been continually expanding, as have many other informal quarters in the city.

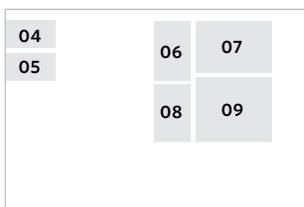
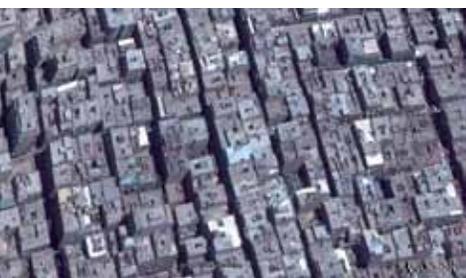


Fig. 04 The houses are built together, generating high-density building aggregates. Google Earth Air view of Ard el Lewa (Cairo, 2010)

Fig. 05 Narrow streets, as in the old town of Cairo. Google Earth Air view of Ard el Lewa (Cairo, 2010)

Fig. 06 In the background: overhanging beams as distance reground; shafts are already envisaged

Fig. 07 Some slots along the facades. Sooner or later this building section will be extended without any clearance

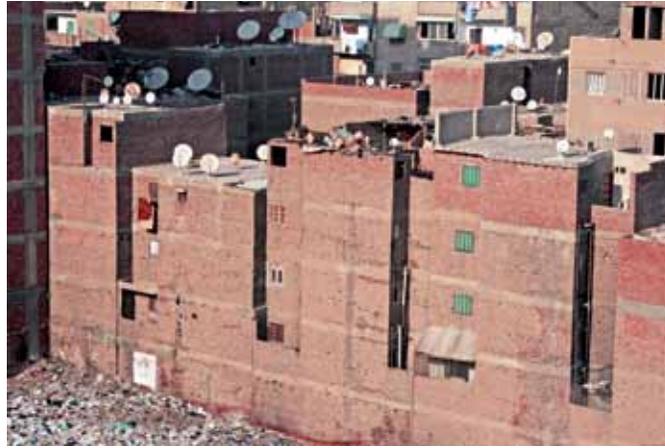
Fig. 08 View into a shaft of a newly constructed building

Fig. 09 View into a shaft of an old informal building from the 1970s

The informal building typology in Cairo generates high-density building aggregates that are extended horizontally, without any clearance, by repeatedly building new sections (Fig. 04). In Cairo, this typology not only reflects the former urban fabric as it is still visible in the Old town, but also the former pattern of land ownership of the agricultural land on which the informal settlements are mostly built (Fig. 05). Quarters like *Boulaq el Dakrou* are some of the most dense places in the world. The Google Earth map of *Ard el Lewa* reveals the specific structure of the informal quarters that have so much in common with old Arabic cities (Fig. 06). In principle windowless on three sides, the numerous recesses, notches and slots along the facades and in the interiors of the informal buildings provide natural ventilation and illuminate the (otherwise) stuffy and dark rooms (Fig. 07, 08). If the slot dimensions are of the appropriate size a ventilation system is established and the apartment interiors are cooled by natural means (Fig. 09). The slots along the facades are indicators of how the urban fabric might develop in the future. Against the topos of “spontaneous architecture”, there is in fact both foresight and logic in informal building practices.

The layout of many informal apartments does not ensure a controlled wind flow, a circulation of which would bring both fresh air inside and heated air outside. The slots and shafts of the informal buildings lack the efficiency of the traditional Egyptian *malqaf*, the wind catcher tower of the old residential buildings. Unlike the thick-walled houses of the old town, today’s informal column-plate structures have little storage capacity. The traditional interplay of natural ventilation and heat storage cannot be activated by these modern (filigree) structures.

These limited observations and remarks should be enough to indicate how many problems have to be solved by architects in order to make structural typologies such as those discussed truly thermodynamically efficient. Nevertheless, in terms of climatic response the informal high-rise buildings in Ard el Lewa have to be seen in continuity with the Arab-Egyptian *courtyard houses*. Regarding natural ventilation, my fieldwork revealed surprising conceptual continuities between the vernacular house types of the region and the contemporary informal buildings. The informal building structures therefore provide clues about how the modernisation of traditional air conditioning practices should be further developed by architects today. Informal cooling strategies are an indicator for new (low tech) architectural cooling concepts – in developing countries and beyond. Contemporary low-tech architectural strategies have to be informed by vernacular and informal building traditions in order to achieve their full effectivity, not only technically but also socially, and culturally. In Cairo, there is a whole culture of making use of natural energy within buildings, a culture which is very much related to social status. Today, people using natural energy are either poor or rich. It’s time to make natural ventilation accessible again to everybody, worldwide.



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Fig. 03-04: Google Earth.

Technology Invigorating Architecture

Integrating passive and active systems to increase design freedom and environmental performance of buildings

Prof. Dr. Forrest Meggers,
Marcel Bruelisauer
FCL Research Module:
Low Exergy

There is a growing desire to design buildings that address concerns about energy consumption, global warming and environmental impacts. This has led to widespread adoption of concepts like green buildings and ecological design, especially in places like Singapore, where green is rapidly becoming a symbol of status and quality design. But we must ask ourselves how these concepts are defined.

Active vs passive solutions

What does it take to produce a “green” building design? Many designers suggest a move away from technical systems, and a return to passive building design, re-discovering and re-evaluating vernacular design features like the building orientation to sun and wind. A popular way to achieve green currently in Singapore is to add greenery (Chua, 2013), green roofs and vertical greenery – the extension of the Garden City from the urban to the building scale. As ecological aspects of design they help shade surfaces, absorb storm water and ameliorate the outdoor microclimate, but their impact on the performance of a building – its resource consumption, energy use, and greenhouse gas emissions – is negligible.

This move toward passive systems as green strategies is quite common among architects and planners. It goes beyond the cliché of making the building green with plants, and it does incorporate important design strategies like appropriate and effective shading systems, daylight maximisation and natural ventilation optimization. Nevertheless, the focus on passive systems has led to a simultaneous neglect of the significant impact of the active systems, which still remain due to comfort expectations by users, regardless of any desire to eliminate these systems and move toward

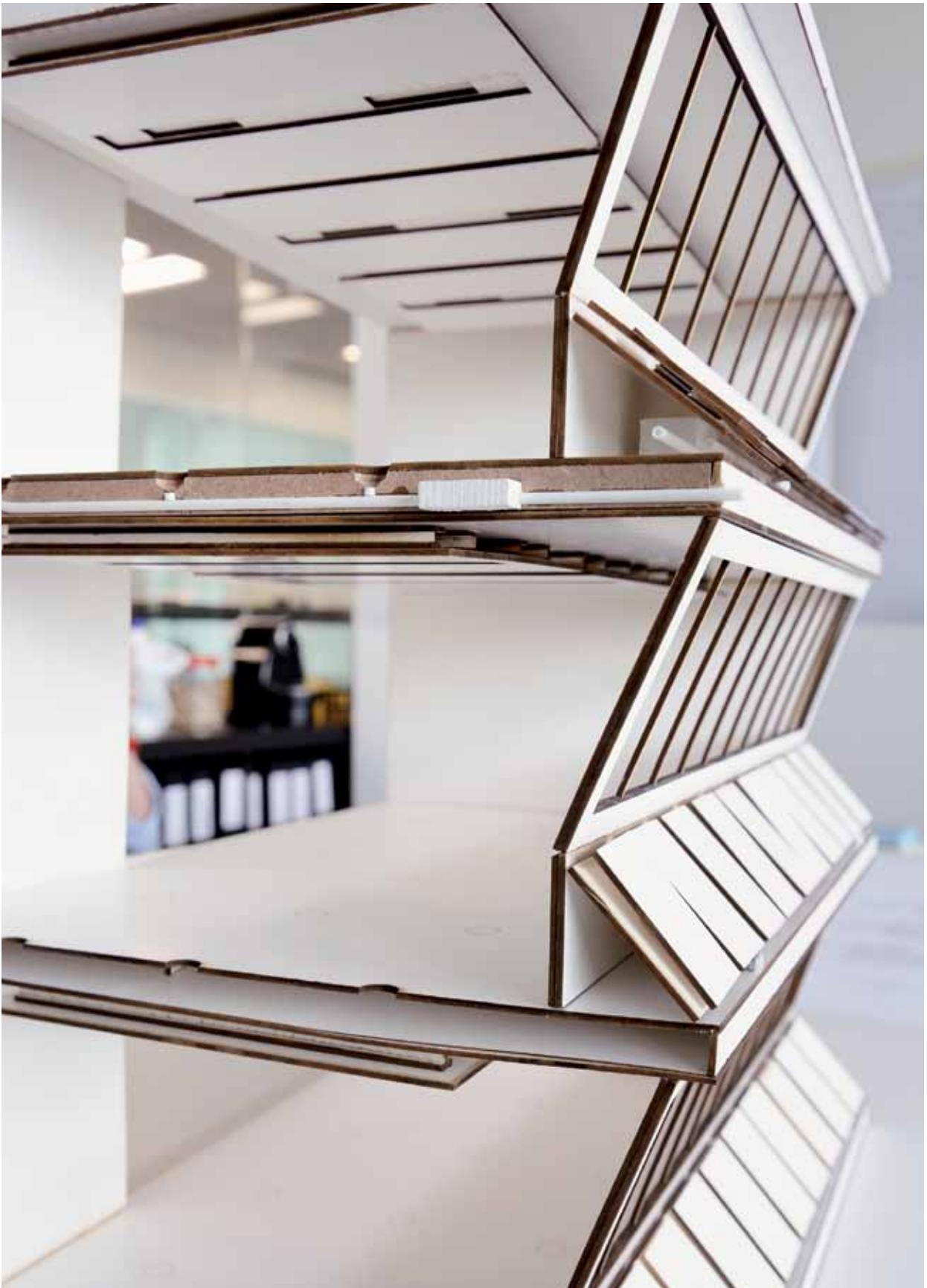
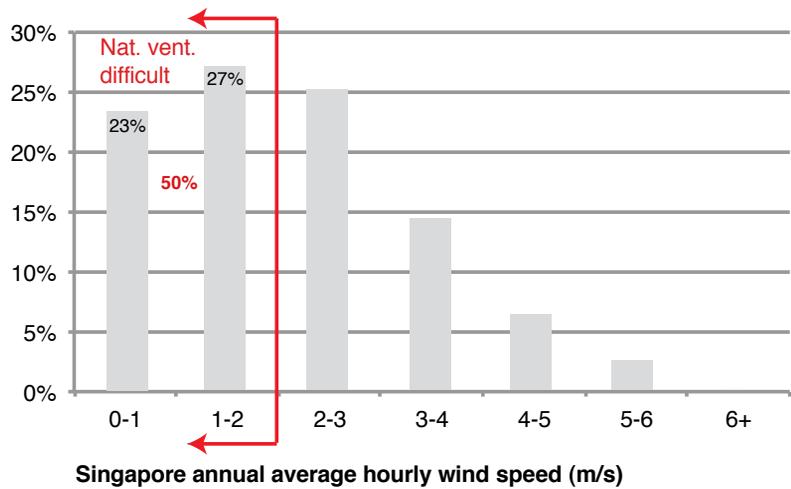


Fig. 01 Model of a Low Exergy design approach

passive architecture. In Singapore, an excellent design for cross-ventilation, even on a high story, will only receive adequate air movement for comfort for roughly half the year as shown in Fig. O2 (ASHRAE, 2001). The other half of the year, the user will be left desiring an active system. This is never addressed when architects present their passive solutions in Singapore. More often than not the failure of airflow will not lead to the purchase of a simple active and highly energy-efficient fan, but rather a split type air-conditioner, and even in condos designed for passive ventilation, split units are installed by default. Ironically, conscientious building users with air-conditioning will now keep the windows closed to reduce energy wastage, voiding any benefit of cross ventilation. Although the closed windows limit energy wastage from air-conditioning, a fan can run with up to 1000 times less energy than a common room air conditioner, yet this option is often skipped over when going switching from a passive to an active system.

Fig. O2 Distribution of wind speeds in Singapore over the year: Even if designed for cross-ventilation, the speed of the air movement inside the building will only be a fraction of the wind speed



At the same time, many engineers look at the same building and see only the potential of increasing the machine efficiency. The focus is often only on providing enough capacity to cool the room to a maximum of 22 °C, and doing so using the most efficient refrigeration system possible. Over the last 25 years, average chiller efficiency has increased by 35%, which may seem like a lot, but by considering the entire cooling system including operation temperatures, we can increase performance by more than 40% (Meggers, Baldini, et al., 2012; Bruelisauer, Chen, et al., 2013), and when we combine novel ventilation and dehumidification techniques we have the potential to double the performance (Meggers and Bruelisauer, 2013).

In order to successfully move to building designs that significantly reduce the environmental impact, it is essential to be aware of the potential of both passive and active systems. They can help or hinder the performance of a building in terms of both energy and comfort. By addressing both aspects of design instead of just passive (as architects often do) or just active (as engineers often do), we can achieve much higher levels of performance that go far beyond what each discipline feels is best practice today.

BEYOND EFFICIENCY

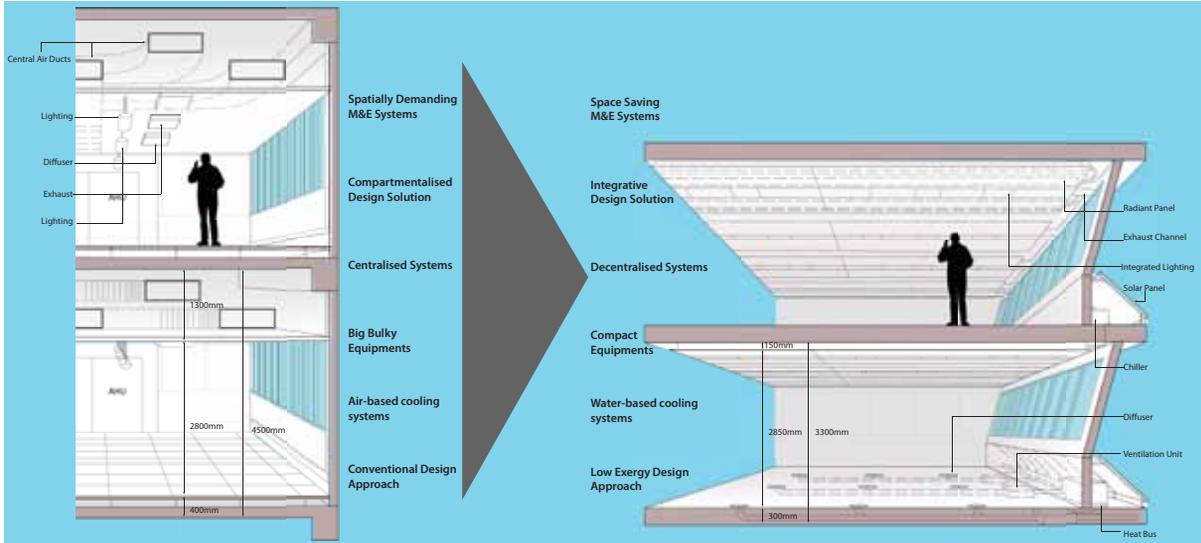
more value more performance more space
less cost less material less volume



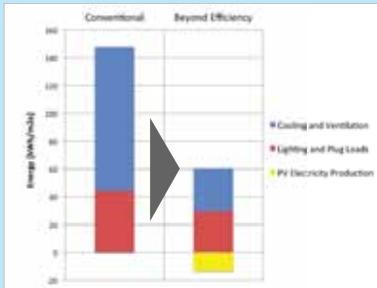
BEYOND EFFICIENCY is a new paradigm for buildings in the tropics - based upon new technologies and integrative design. Radically rethinking / reassembling / redesigning buildings as systems offers new pathways of increased environmental performance and value creation at lower cost, while providing more comfort.

CONVENTIONAL DESIGN

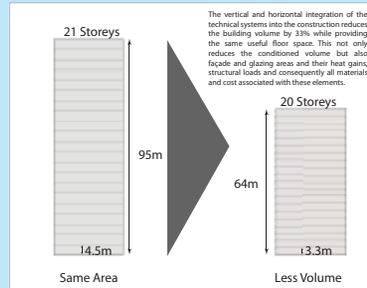
BEYOND EFFICIENCY



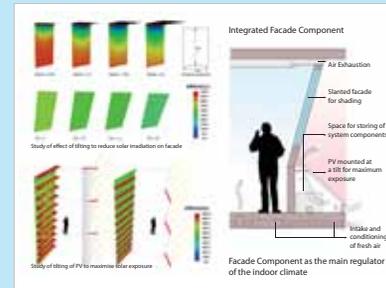
ENERGY PERFORMANCE: 3 X BETTER



SAME SPACE - LESS VOLUME

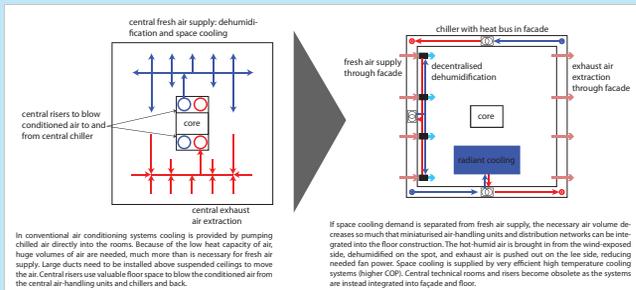


DESIGN INTEGRATION: FAÇADE IS MORE THAN AN ENVELOPE

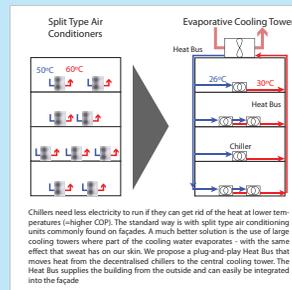


CENTRALISATION

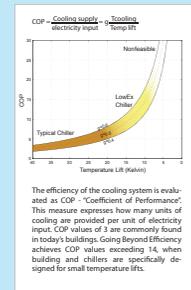
DECENTRALISATION, MINIATURISATION AND SYSTEM INTEGRATION



HEAT REJECTION: MORE SWEAT



PERFORMANCE: COP



CHEN Kian Wee
Marcel BRUELSAUER

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zürich

(SEC) SINGAPORE-ETH 新加坡-ETH
CENTRE 研究中心

(FCL) FUTURE CITIES LABORATORY 未来城市实验室

Fig. 03 Award winning contribution to the Student Poster Competition at the Holcim Forum for Sustainable Construction, Mumbai 2013

Better design freedom with the LowEx paradigm

In practice it is very difficult to apply such a broad set of expertise, we therefore attempt to instil an awareness that facilitates a collaborative development of building form and function, which considers aspects of aesthetic, performance and operation simultaneously. One of the tools we use to do this is the paradigm of low exergy design. LowEx design emphasizes the impact of design decisions on the overall system performance. Instead of considering the individual loss of energy through a wall, and the insulation that is needed to reduce it, the LowEx consideration would connect that loss to the energy supply chain, thereby evaluating the points in the chain to achieve maximum benefit. This may be back at the point of energy generation or at the point of supply, and not at the wall insulation. Exergy represents the essence of the energy that is necessary to drive the heart of the system.

The application of exergy to building system design has been around for the past few decades and was the focus of two International Energy Agency Annexes (IEA ECBCS Annex 37, 2003; IEA ECBCS Annex 49, 2010). We have used the concept at the ETH Zürich to develop new systems (Meggers, Ritter, et al., 2012), and have popularized the paradigm of low exergy in Switzerland (“Neue Wege Zum Nachhaltigen Bauen”, 2011; “Modellfall Sanierung HPZ”, 2011; Röttele and Bachmann, 2011). An excellent example of the different perspective provided by the low exergy paradigm for building design is to consider the insulation of a wall. As shown in Fig. 04, as additional insulation is applied to a standard block wall, the reduction in heat transmission, and thereby building heat (or cool) demand diminishes. If 50 cm of insulation is added, not uncommon for a passive house design, then the last 10 cm of insulation added provides the exact same benefit as the first 1/2 cm that is added, a full 20x reduction in performance, even though the insulation itself remains the same.

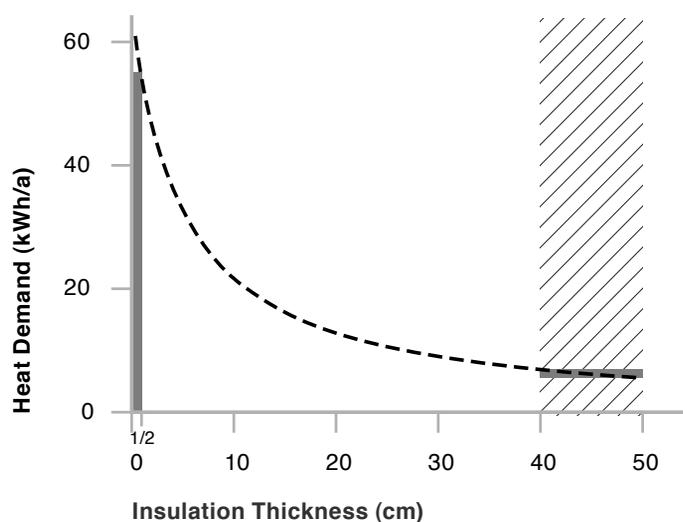


Fig. 04 Diminishing benefit of adding insulation to a building: the last 10 cm of insulation provides the same added benefit at the first 1/2 cm did. 50 cm represents the typical amount of insulation needed to achieve a passive house level of heat demand

By extending the perspective to beyond just the wall of the system to the overall demand, we can see that a high performance wall achieving the performance of the 'passive house' may not always be the most effective solution. It is not to say that the 'passive house' strategy is not an excellent way to reduce energy demand. From a systems perspective, the way it eliminates the need for additional heating systems is another example of how paybacks for good design may come in a different part of the operational chain of the building. But 'passive house' can be quite limiting, especially in the design of the shell, and many architects would feel restricted by the limits placed on aesthetic if 'passive house' would become the standard for façade design.

In Singapore the idea of 'passive house' is a completely different story. The typical 'passive house' cleverly uses internal and solar gains, omitting the need for a heating system, something that applies to the heating context only. The most 'passive house' that can be built in Singapore would be a beach pavilion with no walls, shaded from solar irradiation while maximizing the natural movement of air and its ability to provide comfort via convection. There are no internal "cooling gains" that could be leveraged to create a cooler indoor environment. In the tropics the same heat gains that make 'passive house' possible become the enemy; instead heat has to be constantly removed to the outside.

Uncovering new potential for the topics in Singapore

We have brought this LowEx design paradigm to Singapore and strive to develop new ways of providing adequate cooling and comfort in building spaces with minimal energy demand. We aim to eliminate prescriptive design strategies, which constrain design freedom, and create integrated technological solutions that instead invigorate architectural possibilities and awareness.

Our research aims first and foremost at demonstrating how air-conditioning can be provided with active systems that meet standard cooling demands with far less energy consumption. From that basis, we aim to demonstrate how better comfort can be achieved through integrating passive design strategies with active technical systems, which are themselves aware of the need for a broader definition of comfort and adapt to the spatial and functional context.

The first aim has been studied extensively in our *BubbleZERO* laboratory where we have implemented many LowEx building systems, such as radiant cooling and decentralized ventilation, and where we are evaluating the performance in the tropics (Bruehlisauer, Chen, et al., 2013). Here is where we have confronted one of the largest challenges for tropical building design – humidity. Although temperature is the most widely reported comfort parameter, it is the humidity that is more relevant in the tropics. We have adapted our low exergy systems to address issues of humidity (Meggers, Baldini, and Pantelic, 2011; Iyengar, 2012; Saber, Meggers, and Iyengar, 2013), and we are optimizing their operation while considering new advanced systems for dehumidification that address critical issues in the system operation chain, again based on the LowEx approach.

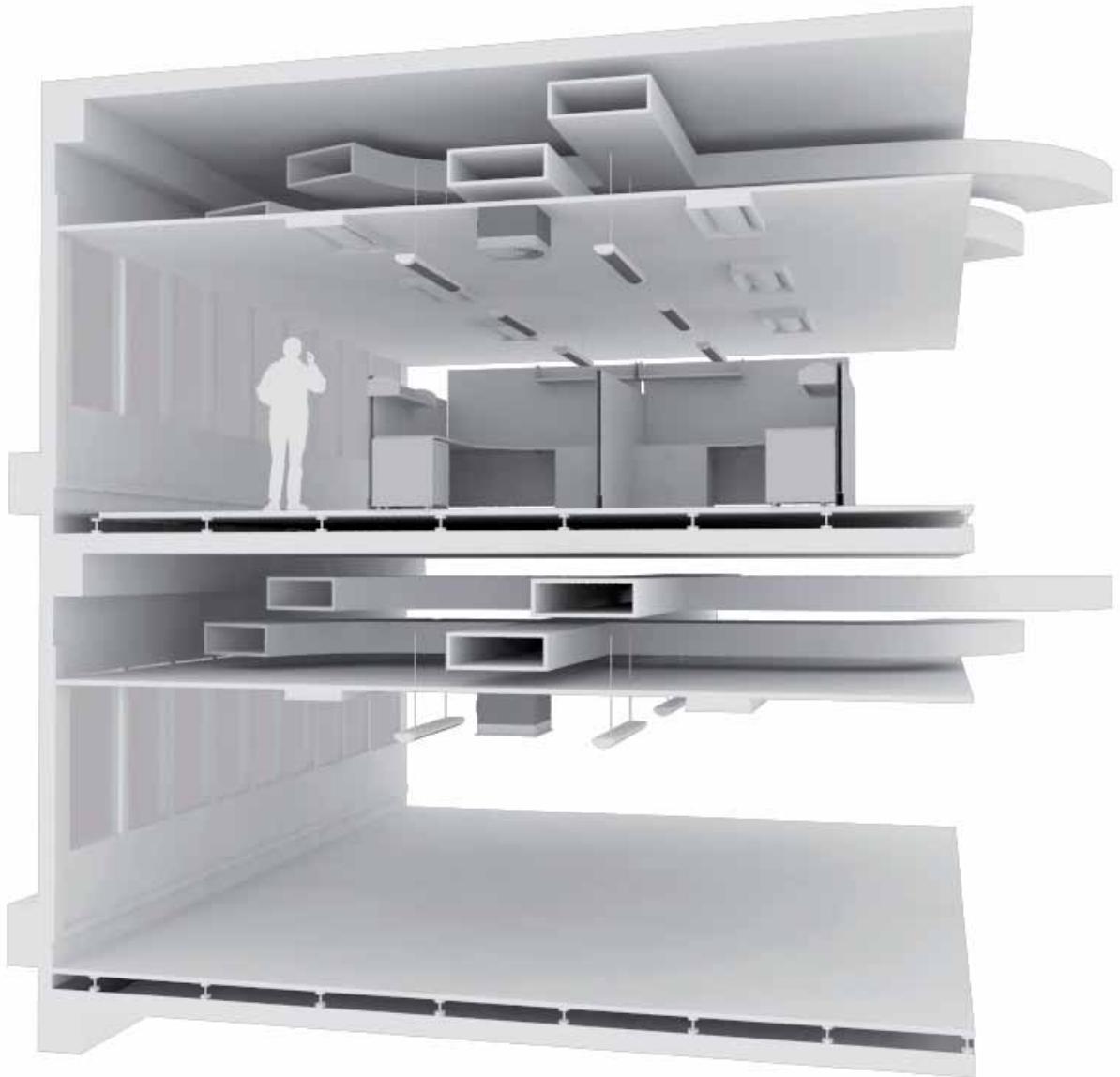


Fig. 05 Conventional design paradigm as observed in the Future Cities Laboratory office building at the campus of the National University of Singapore: The disconnected design paradigm leads to a spatial separation of functionality - structural and mechanical elements, fabric and interior design elements. Cooling is provided by pumping chilled air directly into the rooms. Because of the low heat capacity of air, huge volumes of air are needed, much more than is necessary for fresh air supply, resulting in large ducts installed above suspended ceilings and in central risers. 30% of the building volume is taken up by technical systems, space that is wasted for building users

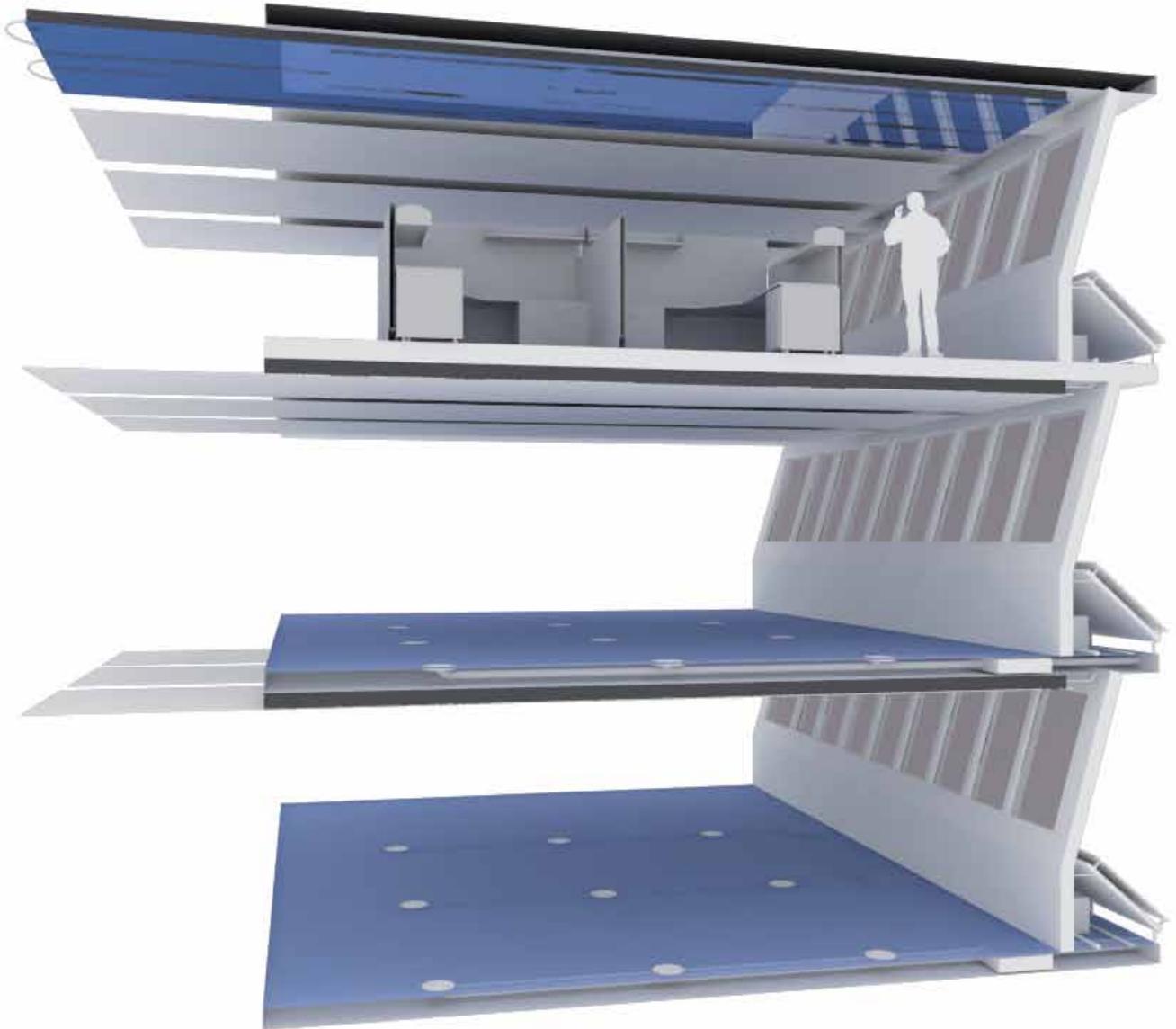


Fig. 06 LowEx design paradigm 342x, physically integrating active and passive elements: Using hydronic piping to thermally activate the concrete slab for space cooling, the necessary airflow for fresh air supply only is reduced so much that the ducting can be integrated into the concrete slab. Technical systems such as air intake and dehumidification, chillers and heat rejection are removed from the building core and integrated into the façade. This new design paradigm will result in a reduction of floor-to-floor height, achieving three floors for the space of two while increasing environmental performance. Less material use and less façade area will lead to additional indirect benefits such as smaller heat gains, ultimately driving down investment and operational cost and create more value

Our more recent success has been on the broader issue of active and passive system consideration. In the standard split type unitary air-conditioners installations we have uncovered a huge gap between designer intention and engineered system installation outcomes (Bruelisauer, Meggers, et al., 2013). These split units are prevalent in all hot-humid areas, available in almost any urban context where cooling might be required. Using novel wireless sensing technology we were able to record the temperature distribution in the space where they are installed. In this case it was a typical scenario where the architect had placed them well hidden from view in a recessed void and behind angled louvers as shown in Fig. O7. The result is that instead of using the outside air temperature to reject the heat from the air-conditioners to, the units at the top of the building receive all the heat from the ones below increasing the temperature by 10+ °C, and on top of that the louvers trap the rejected heat causing another 10+ °C temperature rise. This reduces the performance of the machines well below the values that are expected for this Green Mark Platinum (BCA 2012) installation, labeled based on standard rated conditions, and it is a perfect example of a lack of understanding of the effect on the passive airflows caused by the active system leading to a drastic underperformance.

We have developed new design concepts, physically integrating active and passive elements. By integrating the ventilation ducting into the concrete slab while at the same time using hydronic piping to thermally activate the slab for cooling we can install the same cooling services into a space of around 30 cm that is often more than 2 m, as is the case for the Future Cities Laboratory office building at the campus of the National University of Singapore. The office building is very well designed in terms of energy performance, with high performance individual systems that meet the Green Mark Gold standard. But there is an enormous potential that can be realized if systems are considered together. In this case the structural elements of design can be integrated with the mechanical systems, eliminating the need for a plenum space, architecturally opening up the space for potentially higher ceilings, or allowing the construction of more floors in the same height. In the building we estimate that we could build 3 floors in the space of 2, thus spawning the designation we've given the concept: 342x.

We have embarked on an effort to increase the performance of cooling systems in the tropics using a LowEx design paradigm that we brought with us from Switzerland, along with proven technologies to test in this very different environment. What we have discovered goes beyond technologies themselves, and helps us to better understand the potential of integrated design. A common understanding of the linkages between passive and active systems and to the actual comfort expectations in building spaces can lead to spectacular gains in performance of design and operation.



Fig. 07 Kent Vale residential tower block where split unit location was studied

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- Fig. 01: FCL Singapore.
- Fig. 02-04, 07: Forrest Meggers, Marcel Bruelisauer, Kian Wee Chien.
- Fig. 05-06: Tobias Wullschleger.

Unmanned Aerial Vehicles at FCL

Generating a three dimensional campus model with the support of flying robots

Prof. em Dr. Armin Gruen
FCL Research Module:
Simulation Platform

Drones, also called UAVs (Unmanned Aerial Vehicles) are not only used in the military domain, but there are also plenty of civilian applications. The Geomatics group at the Future Cities Laboratory is currently applying UAV technologies to produce a high-resolution three dimensional digital model of the campus of the National University of Singapore. The project has collected almost 900 aerial UAV images with a resolution of 5cm, from which part of the campus model is derived. This data is amended by point clouds produced by laser-scanners mounted on a terrestrial Mobile Mapping System and terrestrial images, in order to get access to information which is not visible from aerial images. This multi-data approach is a first for Singapore and probably also for the rest of the world.



Fig. 01 Unmanned Aerial Vehicle AscTec Falcon-8

UAVs (Unmanned Aerial Vehicles), or “Drones”, as they are publicly called, have recently received much publicity in the media and attention in scientific-technical circles. It is not by accident that the Prime Minister of Singapore Mr Lee Hsien Loong mentioned UAVs as a key breakthrough technology for the next 20 years in his speech at the 2012 National Day Rally. He said: “UAVs will have many uses in the future – civilian and military”.

Currently, there are essentially three groups of users of UAVs: military, scientific-technical experts, amateurs and model flight enthusiasts. The market of applications and users is very diversified and so are the systems. Nowadays, we have a great variety of UAVs available – from fairly large model helicopters and heavysset model airplanes to tiny, insect-like models that can take off from the palm of your hand.

In professional civilian applications, mostly “micro”-systems are used. These come with an operation radius of about 250 - 1000 meters, a maximum payload of 0.5 - 5 kg and a flying time of 20 - 70 minutes. There are single blade helicopter-type systems, but also quadro-copters, octo-copters (with 8 blades) and fixed wing (model airplane) systems available. UAVs for civilian use are typically produced by small dedicated companies, very often spin-offs from University research institutes. What makes them different from off-the-shelf toy platforms are the integrated sensors: GPS and IMU (Inertial Measurement Unit), electronic compass and height sensor, autopilot and off-the-shelf digital camera. With such highly developed tools, these UAVs can position themselves automatically, fly along a pre-programmed flight path, and take pictures of objects of interest. They can monitor the effect of natural and man-made hazards like oil spills at the harbour and flooding of the city’s roads, in real-time and produce maps and computer models of cultural

heritage sites, hotels, golf courses or city neighbourhoods. They can also be used to detect breeding grounds of mosquitos that spread dengue fever on the roof of buildings which are otherwise hard to reach.

The FCL team around Prof. em. Dr. Armin Gruen has produced more than 800 aerial images of the NUS campus. These images are used to generate a three dimensional digital model of the campus, including buildings, roads and other man-made objects, trees and a model of the terrain –everything done in three dimensions. In this project, high-resolution data of various types (images and point clouds) over the NUS (National University of Singapore) campus area was collected. With this data, methods of three dimensional data processing for city model generation could be exercised and further developed and refined. The input of our work is: (1) UAV images; (2) raw point clouds from a Mobile Mapping System (MMS); (3) few Ground Control Points (GCPs); (4) optional: Terrestrial images for geometric modelling of façades and texture mapping.

The UAV's role of the project is described in much detail in Qin et al., 2012, while the integrated processing of aerial and terrestrial image data and laser-scan point clouds from a Mobile Mapping mission is addressed in Huang et al., 2013. From the last publication we take the main workflow of this project as follows:

- (a) Aerial triangulation (geo-referencing) of UAV images
- (b) Integration of UAV-derived control point data to geo-reference and adjust the Mobile Mapping System point cloud data
- (c) Modelling of the roof landscape from UAV images
- (d) Measurement of the Digital Terrain Model from UAV images
- (e) 3D modelling of façades from Mobile Mapping System data and (if needed) from terrestrial images
- (f) Modelling of Digital Terrain Model from UAV images and Mobile Mapping System data
- (g) Fusing façade and roof models and the Digital Terrain Models to generate a complete geometry model
- (h) Optional: Texture mapping from aerial and terrestrial images

From the input image data, control points and raw point cloud data, we can derive a complete three dimensional site model, achieved by integration of these input data sources.

The modelling area covers approximately 2.2 km². This may not be a large area in mapping, but considering the restricted flying height of 150 meters and a camera constant of 16 mm with off-the-shelf cameras, we obtained 857 images in total with a pixel size of 5 cm. There was another restriction concerning the flight: the UAV was not allowed to fly across the major public roads and should stay strictly within the campus boundaries, which splits the whole areas into 3 parts. This required the flight path to follow the border of the campus closely.

The AscTec Falcon-8 (Fig. 01) was used for the mission. It is a two-beam octocopter with 4 rotors on each side, powered by battery. It has a build-in Global Positioning System GPS and a Inertial Measurement Unit IMU, a barometer, electronic compass and stabilizing system for both the camera and the platform. It has up to 300 meters remote controlling distance with a maximal operation slot of 20 minutes. Since the octocopter needs some power to keep operating, one of the biggest challenges is the short operation time. Due to signal disturbance and unexpected circumstances like strong wind, loss of connection, etc. we only took a maximum of 25 images per flight for safety reasons, sometimes even less, especially when the flight was operated near the boundary of the mapping area. Fig. 02 shows a small sub-block of a bigger building complex.



Fig. 02 A 4x4 sub-block of the NUS UAV aerial image campus block

The first step in data processing is georeferencing/triangulation. This could be done with an accuracy of 1.3 pixels (7 cm in planimetry, 6 cm in height).

For the modelling of the roof landscape we used *Cyber-City Modeller* (Gruen and Wang, 1998). It is a semi-automatic procedure. While the key roof points are measured manually in stereo mode, the software fits the topology automatically. Given that semi-ordered point clouds are measured in a digital workstation following a set of criteria, it automatically generates roof faces and wall faces, where only a small amount of post-editing is needed. It greatly reduces the operation time for constructing building models and can generate thousands of buildings with a fairly small work force. It is also invariant to model resolution, and is able to generate finer details on building roofs such as air-condition boxes, water tanks, etc.

Since Singapore is a tropical country with a large amount of tree canopy around the city, we face difficulties in Digital Terrain Model measurement, especially with images taken at such low altitude of 150 m. Green plants lead to many occlusions. Therefore, for areas where there are trees, the required Digital Terrain Model resolution cannot be guaranteed. In this scenario, to build an accurate terrain model even under the plant canopy, extra information is needed. We obtained this information by acquiring Light Detection and Ranging (LiDAR) point clouds from a Mobile Mapping System (RIEGL VMX 250), driving around campus. The LiDAR points are used to assist in building a precise terrain model under the trees along the roads and also to derive three dimensional façade models. For this latter purpose we also have acquired terrestrial images in photogrammetric mode. This is work in progress.

Intermediate results of the building models are shown below (Fig. 03). This sequence of images shows the development of models from buildings alone, over a combined Digital Terrain Model with a building model to a hybrid model including textures from UAV images.

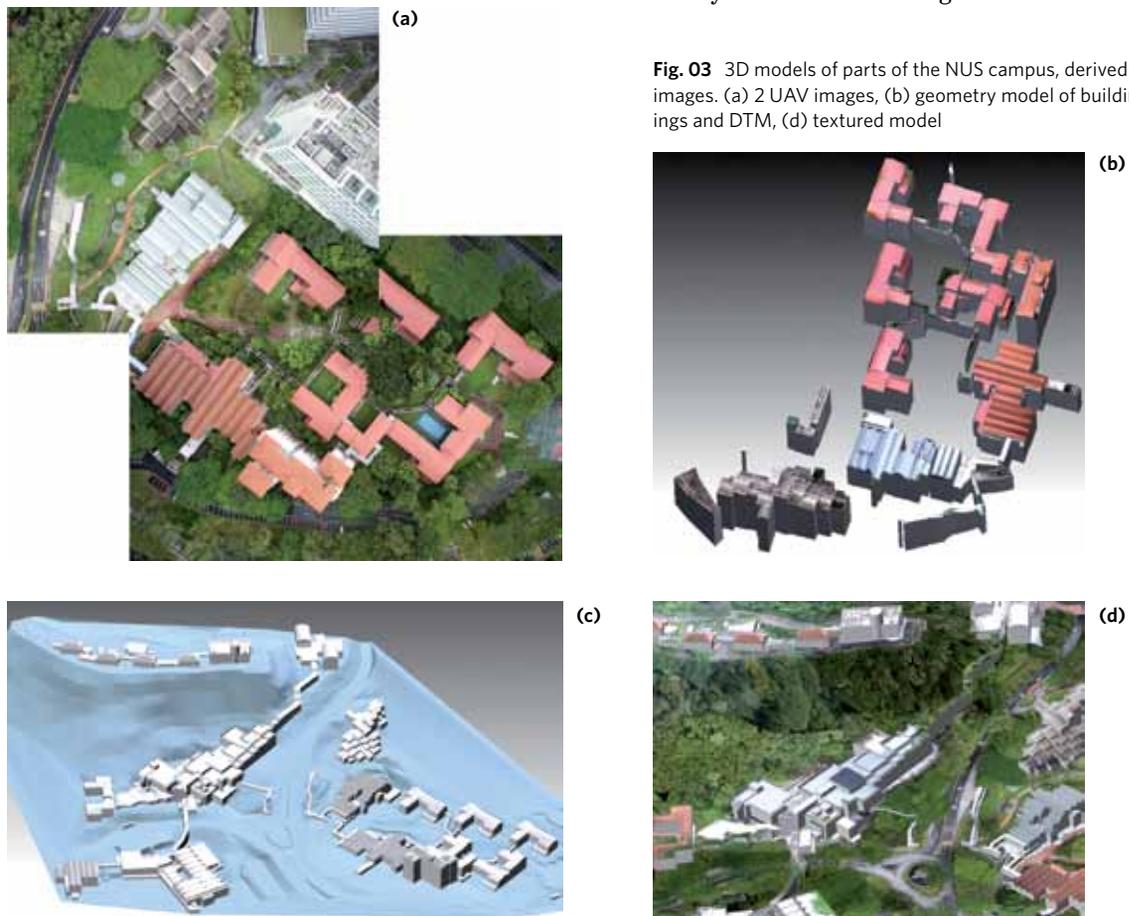


Fig. 03 3D models of parts of the NUS campus, derived from UAV images. (a) 2 UAV images, (b) geometry model of buildings, (c) buildings and DTM, (d) textured model

The model can be used for visualization and as the basis for an information system, useful for a variety of users: campus planners, first-time visitors, hydrology experts who are running a test field, environmental and construction engineers, scientists who are developing autonomous, unmanned vehicles, etc.

There are discussions going on around the world about the proper use and safeguards against malfunctioning drones, both in the military and civilian domains. Apart from the current space race in Asia, with the increasing geopolitical tensions, a drone race may also be developing. The Asian drone market is growing quickly. Frost and Sullivan reports that the region spent US\$ 590 Million on UAVs in 2011. This number is expected to reach US\$ 1.4 Billion by 2017.

While these political, legal and safety-related discussions are going on, the technology develops further. There are efforts underway to make drones more intelligent and more robot-like. This enables them to react to other approaching objects (“obstacle avoidance”), to understand the environment better and thus be able to navigate more autonomously, not just along a pre-programmed route. There is also a significant development towards letting a swarm of drones (“micro-drones”) fly simultaneously and in formation, and having them act like a flock of birds, insects or fish with built-in group intelligence. Very tiny “nano-drones” are being built and also platforms which can fly for days without the need of external energy feed.

The world of UAVs is clearly developing and big steps forward are undertaken from a child’s toy to a heavy duty flying robot, to be used in many ways. The team at FCL sees many more interesting and innovative applications for UAVs in Singapore and beyond and we will actively pursue these opportunities in the near future.

The FCL project breaks new ground as it is the first time that a campus area has been modelled at such high resolution and accuracy. With the experiences gained from this project we look forward to support a larger and more exciting project of developing a “Virtual Singapore”, which would include a 3D model of the whole city – an idea which is stirring the imaginations of many in Singapore.



Fig. 04 UAV in operation at FCL Singapore, CREATE Tower

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Image Credits

Fig. 01-04: Armin Gruen, Qin Rongjun, Huang Xianfeng.

Fig. 05: FCL Singapore.



Fig. 05 Du Tangwu at the digital workstation in the offices of FCL Singapore



Engineering Bamboo

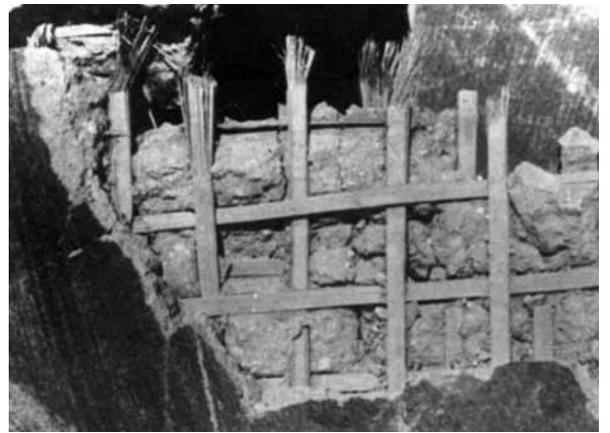
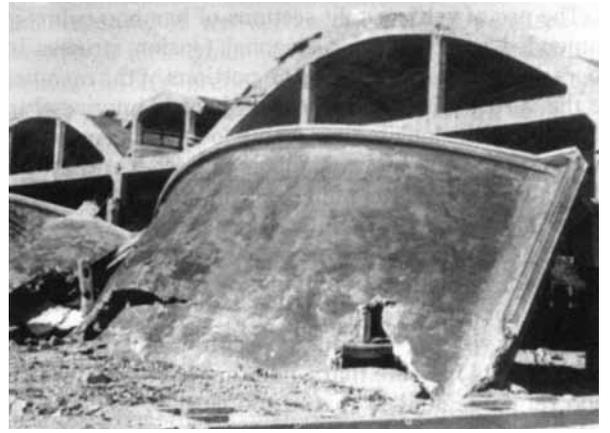
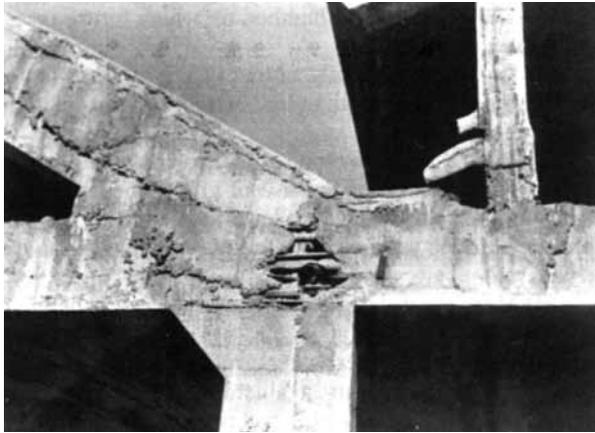
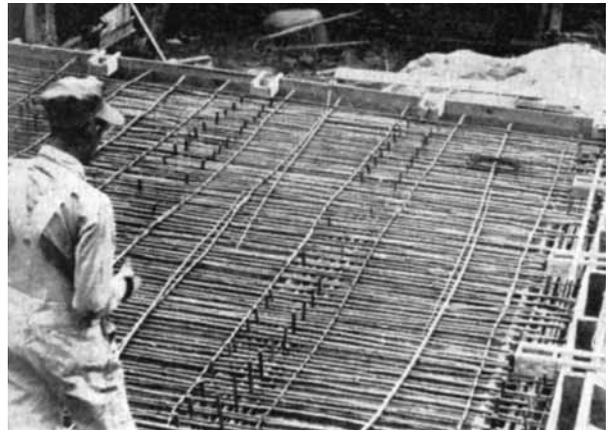
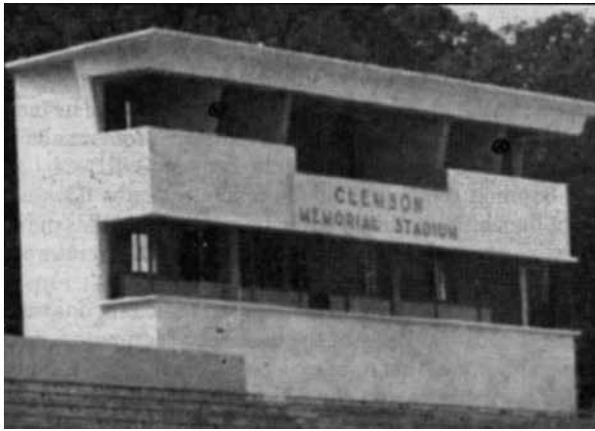
Composite fiber materials as an alternative reinforcement in structural concrete applications

Prof. Dirk E. Hebel, Felix Heisel,
Alireza Javadian
FCL Research Module:
Chair of Architecture and Construction

Bamboo has been used as a construction material for centuries around the globe. The benefits of using bamboo are enormous: its fast growth, high tensile strength, and the capacity to capture large amounts of carbon dioxide from the atmosphere are just some of the most remarkable properties it has to offer. For decades, researchers around the world have searched for methods to activate those benefits for use within the building sector and transform bamboo from a locally applied organic material into an industrialized product. However, water absorption, swelling and shrinking behavior, durability, fungi attacks as well as chemical decomposition of bamboo have limited most of the applications so far. The research at the Chair of Architecture and Construction Dirk E. Hebel at the ETH Future Cities Laboratory Singapore investigates how new bamboo composite materials, developed with the adaptation of already existing technologies, have the possibility to overcome most of these limitations and open new application fields within the building sector, especially in the concrete industry. The technology and machinery for the production of the composite material could be described as 'low-tech', while the research focusing on the development of adequate adhesive and cohesive agents is focusing more and more on the micro level of the material properties.



Fig. 01 Composite bamboo material tensile test



Background

The interest in bamboo as an industrialized construction material can be traced back to the year 1914, when Prof. H. K. Chow tested small diameter bamboo and bamboo splits as a reinforcement material for concrete applications at the MIT Boston. Later, many other research institutions such as the Technische Hochschule Stuttgart in 1935 under K. Datta and Prof. Graf tried to find appropriate applications for the outstanding mechanical and technical properties of bamboo with manageable success. Only in 1950, after World War II, Prof. H. E. Glenn of the Clemson Agricultural College of South Carolina started to conduct more elaborated and extensive research projects on natural bamboo as reinforcement in concrete structures. He and his team actually tested bamboo reinforced concrete applications by building several full-scale buildings utilizing his experience from previous work he conducted in 1944 on bamboo reinforced concrete beams. Using only small diameter culms and bamboo splits, he demonstrated that the application was feasible in principal, however, with regards to modules of elasticity, insect and fungus attacks, coefficient of thermal expansion, shrinking and also swelling, the bamboo reinforcement showed major drawbacks and failures. Structures that were build using natural bamboo as reinforcement collapsed some time after construction, due to de-bonding effects between the natural bamboo and the concrete mix. After those devastating results, the research came almost to a full stop

Only in 1995, Professor Khosrow Ghavami of the Pontificia Universidade Catolica in Rio de Janeiro started again a series of mechanical tests on seven different types of bamboo in order to find the most appropriate species to be used as reinforcement in newly developed lightweight concrete beams. The concrete beam reinforced with natural bamboo splits showed a remarkable increase in the ultimate applied load compared to the beam reinforced with steel bars. This proved that it is possible in laboratory conditions to activate the load bearing capacity of bamboo inside a concrete application. However, the long-term behavior of bamboo in concrete structures was not explained. The different thermal expansion coefficient of natural bamboo and concrete mix will automatically result in the de-bonding of the two materials. Since bamboo is a natural material, its exposure to a concrete matrix will also result in water absorption from the concrete, leading to a progressive de-bonding of the bamboo from the concrete matrix due to excessive swelling and shrinking. This expansion of the volume will also create mini cracking in the concrete, weakening the structure more and more over time and allowing biological attacks on the natural bamboo.

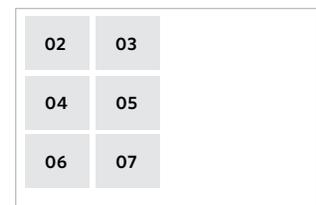


Fig. 02-03 Early application of bamboo as reinforcement in concrete by Prof. Glenn in 1950

Fig. 04-07 Failure of bamboo reinforced concrete, research done by Prof. Glenn in 1950

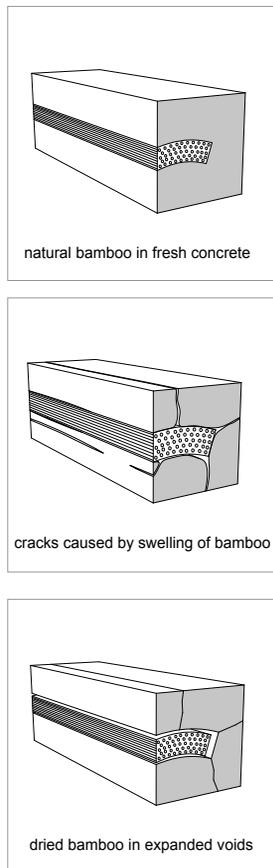


Fig. 08 Swelling of untreated natural bamboo used as reinforcement in concrete

Taking these limitations into account, Woven Strand Bamboo (WSB), a new technology developed only in recent years in Southern China, could point into an alternative direction how to think of bamboo as a composite material, activating its incredible physical properties while controlling the restraining factors. Producing WSB as it is traditionally done in China, natural processed bamboo and adhesive together form a water-resistant, non-swelling and durable composite material. For production, bamboo culms are sliced lengthwise into splits after harvesting and drying and finally processed into strands. This step includes the removal of any external skin, as well as the inner tabasheer and knots. The strands are carbonized and submerged into a pool of adhesive. Placed into molds, these strands are pressed either hot or cold into blocks. The final product reaches a density, which is roughly three times higher than the natural bamboo culm and can be found in hardware stores around the world as flooring material for outdoor use on terraces or walkways. Its water, fungi, and bacterial attack resistance make it an attractive material.

At the Chair of Architecture and Construction of the Future Cities Laboratory in Singapore, extensive research is under way to investigate the possibility to use the described technology as a starting point of investigation and adapt it for the production of a renewable reinforcement material. The advantages would be immense: bamboo is extremely resistant to tensile stress and is therefore one of nature's most extreme products. In principle, bamboo is with regard to its mechanical-technological properties superior to timber and even to reinforcement steel in terms of the ratio of live-load and dead-weight (Dunkelberg, 1985). Bamboo grows much faster than wood, is usually available in great quantities and it is easy to obtain. It is also known for its unrivalled capacity to capture carbon and could therefore play an important role in reducing CO₂ emissions world-wide.

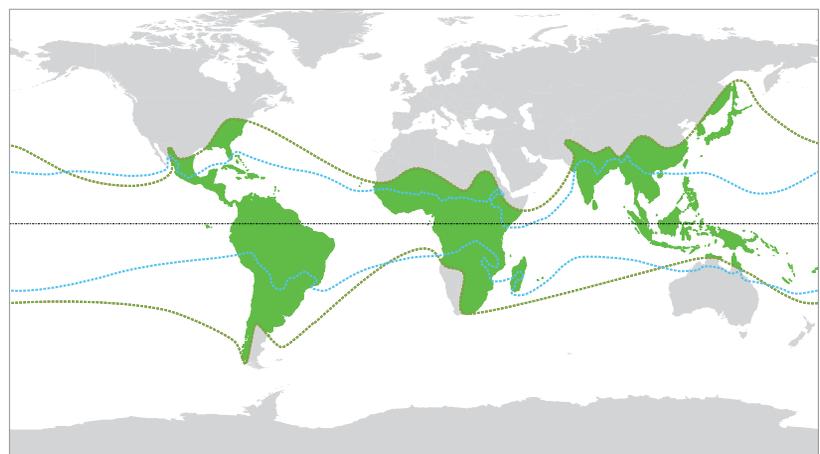


Fig. 09 Green line: Global natural bamboo habitat (information from National Geographic, 1980), Blue line: World's tropical zone

Most developing territories today with an ever-growing population and urbanization rate and with it an ever-increasing need for housing structures, are to be found in a belt around the equator. And also here, bamboo is usually the fastest growing, affordable and locally available natural resource. Attention has to be given to the immense variety of bamboo. World wide, approximately 1400 species are known which show quite different material properties.

First test results at FCL Singapore indicate that the envisioned adaptations in the already existing production lines of WSB could actually address and control the most crucial factors of the material behavior. One of the research interests is focused on the question how the production process of WSB technology can be changed to avoid the individual bamboo fiber or cell being harmed or even degraded. This is in contrast to the furniture and flooring industry in China, where the individual fiber or cell is not of interest at all and usually destroyed through carbonization processes to eliminate all natural sugar in the bamboo material to be unattractive for fungi and bacteria. But considering the tensile strength as the crucial property when it comes to reinforcement applications of the material, alternative treatments have to be investigated. Therefore the work tries to establish gentle treatment methods that are easy to be up-scaled in mass applications. Focus is given also on the surface character of the bamboo fibers in conjunction with adhesive agents. Here, adhesive (between components) as well as cohesive (inside components) features have to be understood and enhanced compared to the already existing technology. But also the adhesive agent as such is part of the investigation. In collaboration with one of the biggest adhesive producing companies in Europe, research is under way to find the most appropriate agents for the given purpose. Using confocal fluorescence microscopy, different components of natural fibers can be made visible with a high magnification factor. The adhesive matrix fluoresce differently dependent on the excitation wavelength. With this technology, it is possible to record the spatially resolved fluorescence spectra and exactly determine the interface where the natural bamboo fibers interact with the resin. The distinction of different components is specific and can be done quantitatively in order to develop new technologies and processes to reach the desired mechanical, chemical and physical properties of the composite.

Water and bacterial resistance, thermal expansion, refractability, and up-scaling potential are on the forefront of investigation. In addition, questions of durability need to be addressed simultaneously. A multi-disciplinary team of engineers, chemists, material scientists and architects was formed over the last months at the Chair of Architecture and Construction at FCL to tackle these challenges and with the help of a newly established production laboratory, extensive production and test series are under way. As bamboo is still in most countries a material that is not considered to be the “norm”, standardizations are developed to conduct the research on highest possible scientific terms and form the base of a PhD work currently under way.



Fig. 10 Production component of the Advanced Fiber Composite Laboratory (AFCL) at FCL Singapore





Fig. 11 Composite bamboo material

If successful, the research could provide the base to introduce new and adapted technologies, that take a wide spread natural resource as its basic premise. Today, a ton of bamboo is traded for only a minor fraction of costs compared to steel. In South East Asia alone, the potential for bamboo composite materials considering all areas of bamboo coverage currently, is 25 times higher than today's demand for construction steel. In addition, it is a renewable resource with a very high capacity of carbon absorption. The production technology as such could be characterized as 'low-tech' with injected 'high-tech' knowledge considering the micro structural understanding and interaction of fiber and adhesive agents. On a global view, the natural areas of bamboo habitat are congruent with developing territories. These nations, given their advantage of a tropical climate, could produce an alternative construction material and with it liberate themselves from the current condition of heavy imports of steel. Out of 54 African nations, only two have an established steel industry. Building local value chains could also strengthen rural-urban linkages and establish alternative technologies based on renewable resources as key industries in developing territories. As a "reverse modernism" approach, it would be possible that the so-called "South" could for once be the leading force behind a technological development and export the resulting goods to the so-called "North".

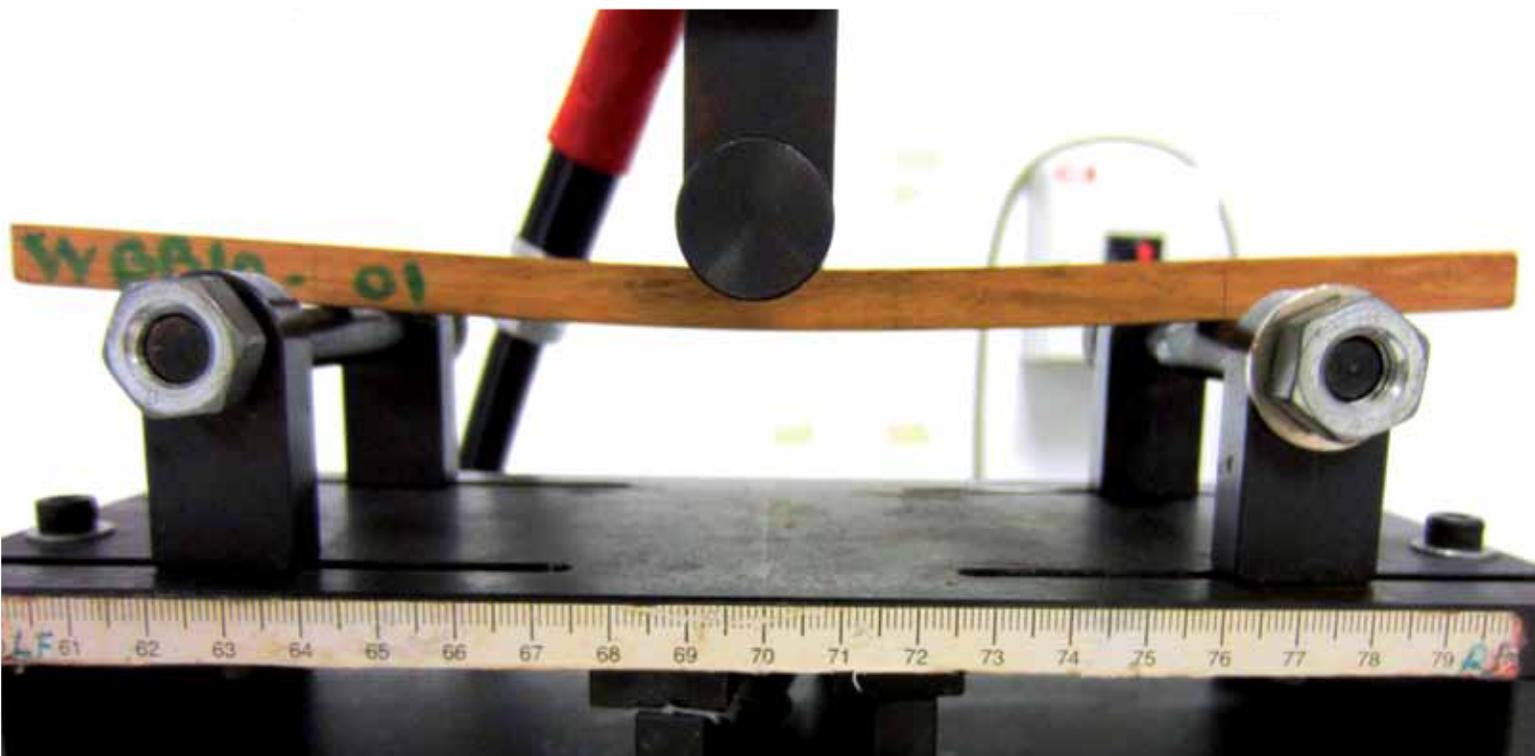


Fig. 12 Three-point bending test at laboratories of NUS Singapore, School of Engineering

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Fig. 02-07 : Lopez, O.H. (2003) *Bamboo The Gift of The GODS*. first ed, ed. O.H. Lopez: D'VINNI LTDA, Bogota, Columbia, page 207-212.

Fig. 08, 11: Felix Heisel, Chair of Architecture and Construction Dirk E. Hebel, ETH Zurich, FCL Singapore, 2013.

Fig. 09: Felix Heisel, Chair of Architecture and Construction Dirk E. Hebel, ETH Zurich, FCL Singapore, 2013, information from National Geographic, 1980.

Fig. 12: Alireza Javadian, Chair of Architecture and Construction Dirk E. Hebel, ETH Zurich, FCL Singapore, 2013, images taken at laboratories of School of Engineering, NUS Singapore.

Fig. 01, 10, 13-14: FCL Singapore.



Fig. 13 Chemical component of the Advanced Fiber Composite Laboratory (AFCL) at FCL Singapore



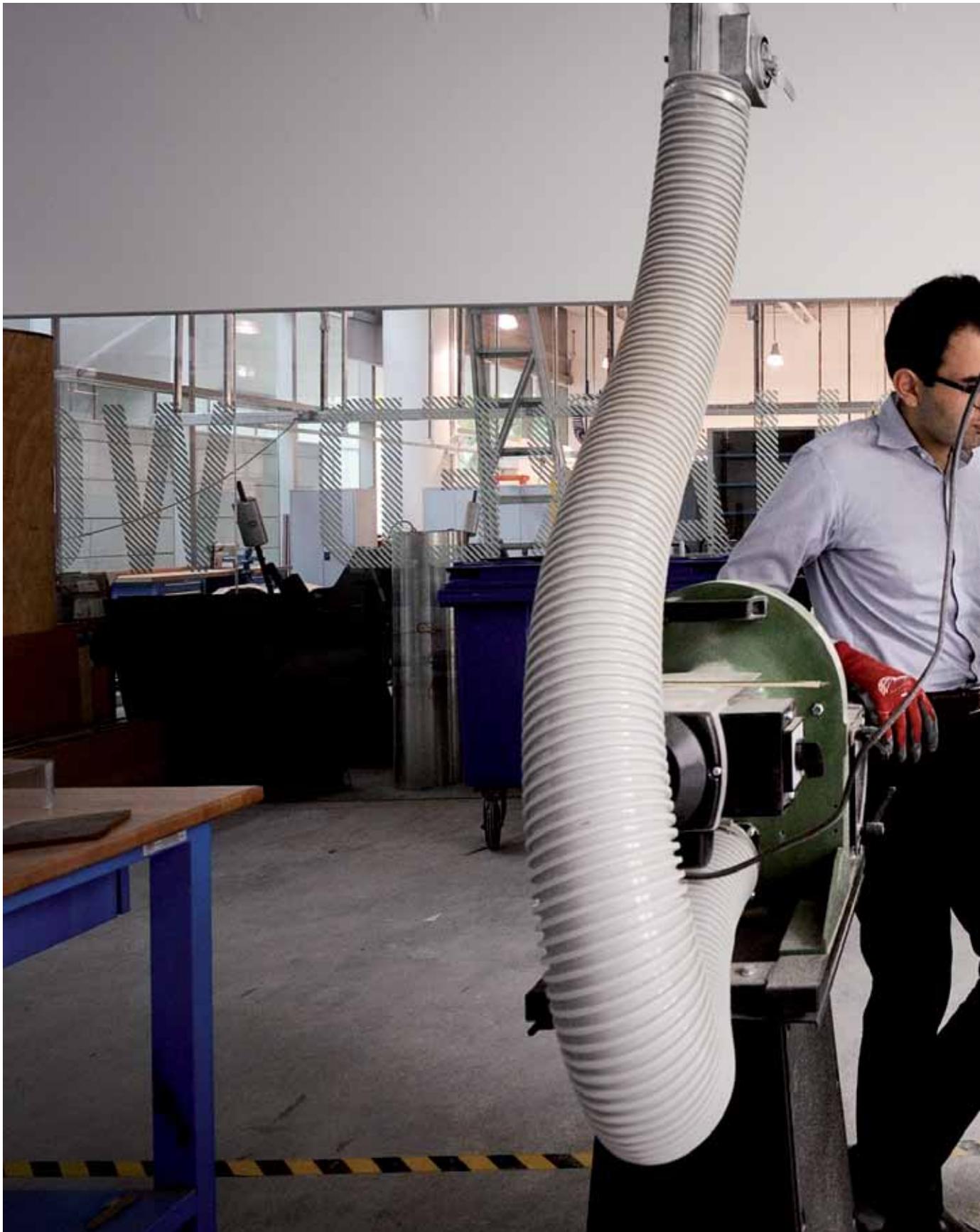


Fig. 14 Preparing test samples in the advanced Fiber Composite Laboratory AFCL at FCL Singapore



Digging Deep

Attempts to monitor groundwater along the Ciliwung River

Kashif Shaad
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Groundwater is an important and often overlooked component in the story of how water moves and interacts with our cities. When we consider the case of Jakarta – a city of population exceeding 10 million with up to 40% (Steinberg, 2007). dependent on groundwater resources to meet its water needs – our understanding of groundwater becomes even more crucial. But to make sound analysis, collection of reliable data is the first and sometimes most difficult step. This article outlines some of the challenges faced by the Landscape Ecology research module of FCL in the field and the solution devised to gain insights into the water issues plaguing Jakarta and its link to the river flowing through its centre.

For our study on the Ciliwung River, we are interested in the river-groundwater interaction that happens in the vicinity of the river. This interaction can be important on two counts. Firstly, as a driver of diffusion of contaminant and pollutants into the water resources, eventually making the groundwater unsuitable for use. And second is to understand the dependency between the river and the groundwater resource in terms of water availability, on which, in turn, the denizens of the area surrounding the river depend. Since we are investigating this impact on the upper layers of the groundwater system – we confined our analysis to about 30 meter below surface level – compared to the approximated depth of 300 meters to which the groundwater system exists. Even with this simplification, we immediately encountered the problem of obtaining data that sheds light on river-groundwater interaction. Most of the data required were either non-existent or unavailable to the research team. This could be overcome by devising our own monitoring campaign by means of deploying standard water level data loggers used for recording temperature and water level changes over a number of months.

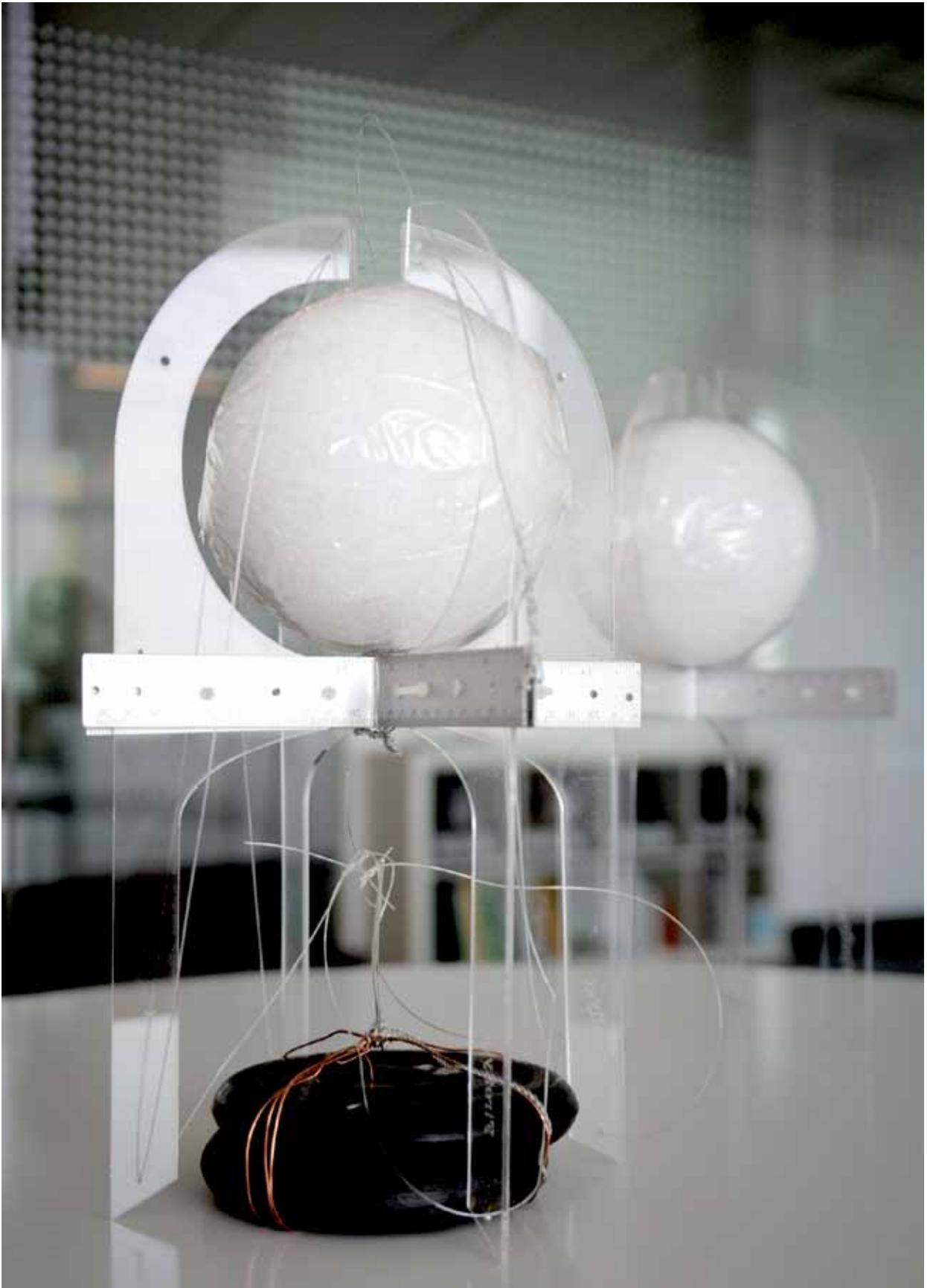


Fig. 01 Assembled 'Firefly' module

However, we faced two main challenges. The first was the location of deployment and second, the method of deploying the data loggers. Unable to drill our own observation wells due to the dense settlements in the river corridor, the first problem was, to some extent solved, by extensive field survey. Work done with help of students from the University of Indonesia (UI) helped identify public open wells that satisfied the criteria of depth, location, etc. required for setting up a long-term monitoring network of groundwater level variation in the river corridor.

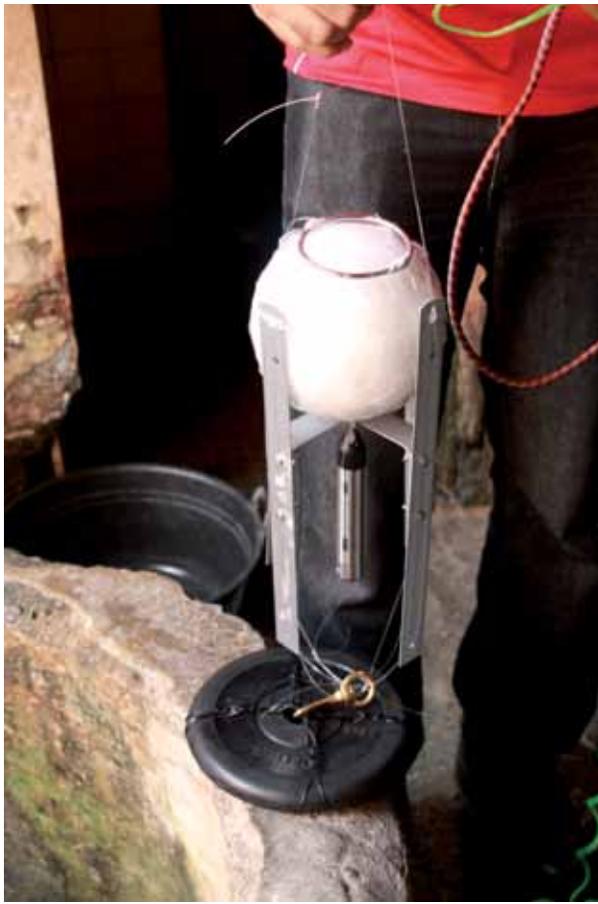
The second problem – deployment method – was a bit more challenging. The standard method of deployment involves tying the data logger securely with steel or other non-deformable rope, lowering it into the observation well and then securing the other end of the rope outside the well in a manner so that the data logger is stable and always underwater. This also makes the probe easily retractable for checking and downloading data from the probe in consequent visits. In this aspect, public wells along the site were ill suited for deployment. Being public open wells, they are completely accessible, used and visited by many people over the course of a day. The rope-based deployment offered no protection to the device and would be highly visible. In a region where scrap metal is lucrative trade and even waste plastic is ‘fished’ from the river for its resale value, we had our reservations about deploying expensive equipment that we were not confident of retrieving. Also, even in the more secluded wells used by only a handful of people, the constant use of the well by means of bucket-pulley system meant that the rope-based deployment might not guarantee stable deployment of the data logger.

During the first eight months of identifying the wells, students from UI diligently went back to the well and measured the levels manually on a weekly or bimonthly basis. As we start to analyse the data, patterns we saw convinced us that investing into the probes, which would record data for us at a much higher frequency, could lead us to a much deeper understanding of the groundwater system and may be a worthwhile risk. However, the standard deployment method was still deemed unsuitable and hence, we were now challenged to come up with a new deployment method that would enable us to deploy the data loggers almost incognito in the wells. This deployment method had to be stable in harsh conditions over long durations and exposure. Also, the material used to make it had to ensure that they do not adversely affect the quality of water in the wells. For this, a simple yet effective submersible probe deployment module was developed – which we named ‘Firefly’.

Designed and manufactured internally, the ‘Firefly’ is basically a weight-float system with a secure cage in the middle for the data logger. The weight provides the strong downward anchor while the float’s buoyant force under water is sufficient to keep the structure erect but just insufficient to lift the weights. This in effect, becomes an auto-correct mechanism



Fig. 02 Orthophoto showing a section of the Ciliwung River snaking through the dense Kampung in Jakarta



– any force that destabilizes the system will be countered as the float tries to stay buoyant – keeping the setup strictly vertical. The advantage of this module is that it is completely autonomous. It needs no anchor to the surface via a rope as the standard deployment does. Yet it can ensure that the data logger remains at a fixed depth above the base of the well, unaffected by the sediment and stable for correctly recording the water level and temperature.

After a month of in-house testing of the material used for constructing the 'Firefly', three devices were constructed and deployed at the onset of the rainy season in our selected wells. After three months, which also saw the devastating January 2013 floods pass through the region (and inundating 2 of our 3 wells), we successfully managed to retrieve all three devices and data loggers. The data retrieved from them gave us interesting insights. For example, the data showed the response of the groundwater system to the extensive flooding over the surface. The effect of low intensity but large scale use of groundwater by household on the water table could also be seen clearly in the records. This data and the method of collection behind it has helped us observe and study the close link of the city to the water resource right under its feet in a new light, and as we explore this region further we hope to convert this data into knowledge for better management of our urban rivers.

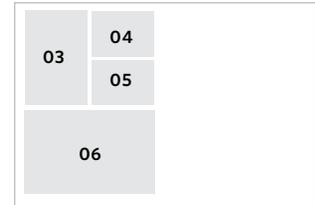


Fig. 03 'Firefly' with data logger mounted ready to be deployed in the open well

Fig. 04 Retrieved after 3 months under water

Fig. 05 Example of a public and open dug well

Fig. 06 The dense urban fabric and its water dependence. Overhead tanks (highlighted in colour) are in most cases connected to a pump extracting water from the ground

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Image Credits

Fig. 01: FCL Singapore.

Fig. 02: FCL Research Module Landscape Ecology.

Fig. 03-05: Kashif Shaad.

The Case of the Ciliwung

Non-conventional approaches to measure water quality in flooding and highly degraded rivers

Diogo da Costa
FCL Research Module:
Landscape Ecology

Rivers, as an integral part of the urban tissue of cities, are often a visible face of poor environmental consciousness. It is very common to see the prevalence of certain poor hygiene related diseases in many cities around the world as the result of extremely degraded water quality conditions. Situations like this are becoming more frequent as many emerging mega-cities are failing to accompany development and growth with basic infrastructures. Vulnerability to floods dramatically aggravates the impact of some of these problems, especially in regions where the floodplains are occupied by poor communities. The city of Jakarta is one such example where the combination of these phenomena frequently occurs. The Ciliwung catchment is home for as many as 5 million people and frequently floods, leaving a trail of destruction and a great portion of the city underwater. Managing the water resources and quality in such a complex environment requires a deep understanding of the dynamics and interactions of surface and ground water systems. Setting up a water quality monitoring campaign is extremely difficult due to excessive pollution and socially sensitive local conditions but is a crucial step in understanding the overall river-groundwater system.



Fig. 01 Probe after one day deployed in the Ciliwung River at Kebon Baru



Monitoring the quality of very polluted waters

Preparing a campaign to monitor the quality of water in most rivers is itself a very demanding job. Rivers are extremely dynamic systems and any monitoring study requires a great deal of preparation, improvisation and adaptation to sometimes rapidly changing and unpredictable river flow conditions. Textbook water quality monitoring campaigns procedures applied to rivers such as the Ciliwung in Jakarta are likely to fail or be susceptible to gross shortcomings if we ignore local conditions. Difficult accessibility to the river, highly polluted waters with both organic matter contamination and plastic (Fig. O1), destitute communities residing on the river banks, floods (Fig. O2 and O3) occurring almost every day during the wet season, makes of conducting a water quality monitoring campaign an exciting but very challenging mission.



Monitoring the water quality is a crucial step in understanding the river's physical, chemical and biological dynamics. Nonetheless, it is these measurements that allow building and calibrating mathematical schemes (known as numerical models) than can be used not only as forecast tools but also to further improve understanding of the "hidden" processes taking place in river waters. Domestic pollution sources are typically assumed as point sources in most urban modelling studies; however this is extremely difficult, if not impossible, in the case of the Ciliwung River. This is due to the fact that nearly every house sitting close to the river discharges its daily wastewaters directly into the Ciliwung, making it practically impossible to accurately identify the location and the amount of water and pollution being discharged.

To add to this complexity, the sewage system coverage in Jakarta is very limited (approximately 2%). This is the reason why most of the domestic wastewater is stored in septic tanks or discharged directly into the river. In the event of a flood, the septic tanks located in the flooded areas are likely to be inundated and potentially hazardous waters, sludge and waste expected to overflow. Finally, it is also very important to take into consideration the years of accumulation of contaminants in the soil – this fact plays a huge role in the overall quality of the water. For that, we developed a mini-reactor (Fig. O4) with the collaboration of the University of Indonesia to quantify the contribution of the organic matter attached to the riverbed's sediments in the overall dissolved oxygen depletion.

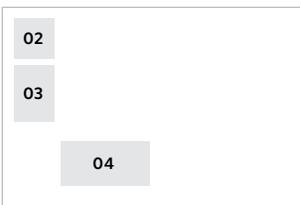


Fig. O2 Probes and reader found underwater after a flood

Fig. O3 Working conditions during a flood event (probes' data retrieval)

Fig. O4 Low budget reactor for calculating oxygen consumption in the river sediments due to long term accumulation of organic matter



Improving understanding of such complex river system

The first set of results obtained is the outcome of arduous fieldwork in Kampong Melayu, Jakarta. Various parameters were monitored, from heavy metals to nutrients, organic matter, coliforms, and many others. The measurements were carried out at 3 different cross-sections to better capture the spatial and temporal distribution of such contaminants. Dissolved oxygen often gives a good indication of the quality of the water for ecosystems and river dwellers require a minimum concentration to survive and reproduce. Low concentrations of dissolved oxygen typically result in unbalanced ecosystems and dominant species.

The system shows to be heavily polluted with very small concentration of dissolved oxygen. It exhibits a slight improvement during the night as a consequence of decreased domestic pollution but as the day goes on and human activity increases, that observation is immediately reversed. The concentration of dissolved oxygen repeatedly drops throughout the day turning the water into a threatening anoxic environment across the entire Kampong Melayu stretch.

Floods bring a great amount of fresh and clean water that helps in diluting the heavily contaminated waters of the Ciliwung. During these events, the concentration of oxygen more than tripled and the augmented flow lasting in the subsequent days shows to be enough to retain the concentration of dissolved oxygen way above the typical small values. In turn, as the river flow returns to its average values, the existing dissolved oxygen is completely depleted.

The measurements carried out with the homemade reactor show that the oxygen consumed by the organic matter attached to the river sediments cannot be neglected. Results indicate that the dissolved oxygen can drop between 20% and 30% in less than 3 hours. This fieldwork is a very important step in understanding the natural and anthropogenic factors affecting the quality of the water in such under pressure and degraded systems. Other campaigns are being prepared in other sites along the river to improved understanding of the system as a whole. Collecting this data is crucial to properly set-up a mathematical forecast model to both the entire river corridor and the different sites. This is of great use and importance to support the development of coherent and effective rehabilitation strategies, to understand the impact of floods in the overall water quality, to identify areas where contaminants are likely to accumulate and to address the issue of river-groundwater contamination exchange.

Image Credits

Fig. 01-04: Diogo da Costa.

Fig. 05: FCL Singapore.



Fig. 05 Office spaces of the Landscape Ecology research module at FCL Singapore



Homemade Suspended Sediment Sampler

An effective low-cost device

Dr. Senthil Gurusamy
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Landscape Ecology

Sediments play a vital role in the fundamental cycle of the aquatic environment. They are responsible for transporting a substantial proportion of many nutrients and contaminants in the form of chemicals and toxic materials. Most of the sediment in surface waters is derived from surface erosion and comprises mineral and organic components. Deposition of sediment in rivers can decrease water depth, making navigation difficult or impossible, thus resulting in more frequent and severe flooding and increased property damage. Increased sedimentation may also have an economic impact on agricultural land, residential property, survival of aquatic species and public water systems. To ensure access, some of the sediment may be dredged from the stream, but this may release toxic chemicals into the environment. To determine how much dredging needs to be done and how often, water levels must be constantly monitored, and the rates of sediment transport and deposition estimated.

There are several numerical models to simulate and estimate the sediment transport, but when it comes to sensible analysis and validation, in-field measurement plays a great role. These measurements are done with the help of commercially available samplers. Sediment measurement involves sampling the water-sediment mixture to determine the mean suspended sediment concentration, particle size distribution, specific gravity, temperature of the water sediment mixture, and other physical and chemical properties of the transported solids.

Suspended sediment concentration in a natural stream varies from the water surface to the streambed and laterally across the stream. This article provides information on how to make a simple, lightweight, low cost, depth integrated suspended sediment sampler. It is made from easy to find parts that can be constructed at a price far below from what you would pay for a commercially made device.

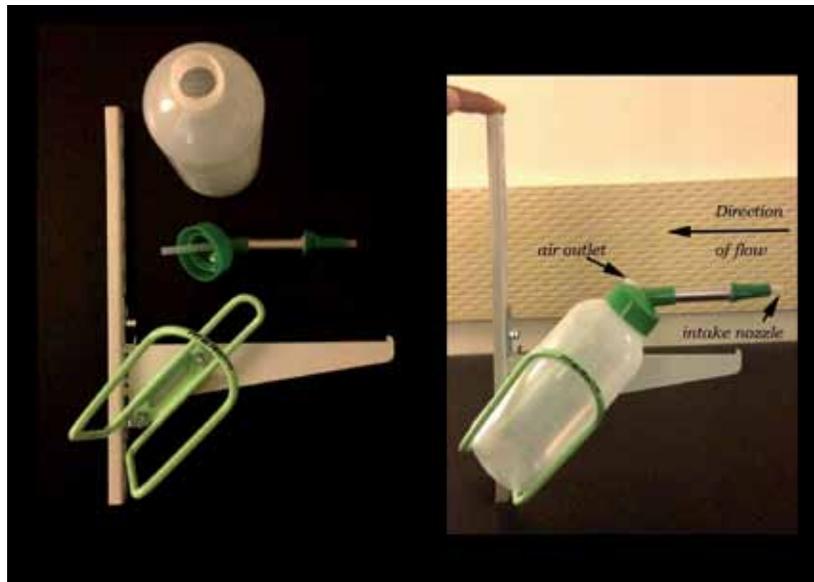
How to construct a depth integrated suspended sediment sampler:



Fig. 01 Material required in constructing the device

Material requirements and steps to build the sampler

The following list contains the common materials required to construct a sediment sampler (Fig. 01): 1) wading rod of varying lengths-25cm, 1m, 2m; 2) L shaped metal stand to fix the bottle cage; 3) Water bottle cage used on bicycles; 4) intake nozzle, standard inside diameter- $\frac{1}{4}$ -inch, $\frac{3}{16}$ -inch or $\frac{1}{8}$ -inch, to let the water through; 5) 500ml plastic or glass bottle, to collect the water sample; 6) bottle cover, holes are drilled to fix the outlet and inlet nozzles; 7) elements to construct the intake nozzle; 8) tool box, equipped with different kind of screws, bolts, nuts and flexible wire; 9) multi-use screw driver; 10) measuring tape; 11) pliers, to fix and tighten the screws and bolts; 12) caliper, used in fixing the nozzle diameter.



Time, cost, and installation

With adequate tools, a depth integrated suspended sampler can be built in less than 15 minutes. The cost of a sampler can be as little as US\$ 12 based on the materials used.

How to use a depth integrated suspended sediment sampler:

The depth-integrating sampler is designed to continuously extract a sample as they are lowered from the water surface to the streambed and returned at a constant rate of travel (Fig. 03-05). Ascending and descending speeds need not be the same, but the rate of travel must be constant in each direction. During the sampling operation, the intake nozzle is orientated into the current and held in a horizontal position. The sampler continues to take its sample throughout the time of submergence. While the sample is collected, air in the container is compressed so that the pressure balances the hydrostatic pressure at the air exhaust and the inflow velocity is approximately equal to the stream velocity.

The transit rate depends on the mean velocity in the vertical, the water depth and the nozzle diameter. Care should be taken such that the sample bottle is filled about 90 per cent of its capacity. The sample bottle (Fig. 06) is then removed, capped and returned to the laboratory where the fluid volume and sediment mass is determined for the calculation of suspended sediment concentration.

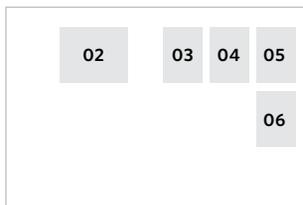


Fig. 02 Sampler after assembling and ready for use

Fig. 03-05 Stages of sampler deployment in the Ciliwung River, Jakarta on May 15, 2013

Fig. 06 An example of suspended sediment collected



Calibration

One of the easiest ways to calibrate the sampler is done with the inflow efficiency flow diagram, which is related to the size of the nozzle diameter used (FISP Report, 1941). The sampler is only suitable for stream depth less than 5 m in which the velocities do not exceed 2.3 m/s.

Conclusion:

The device is a simple, homemade, light weight, low cost depth integrated suspended sediment sampler. The water samples collected from the sampler will help to determine the mean suspended sediment concentration, particle size distribution, specific gravity, temperature of the water sediment mixture, and other physical and chemical properties of the transported solids. The low cost has given more options to construct more samplers collect more data from different sections of the river at the same time.



References

'Laboratory Investigation of Suspended Sediment Samplers', *FISP Report 5*, 1941, St. Paul U.S. Engineer District Sub-Office Hydraulic Laboratory, University of Iowa, Iowa City, Iowa.

Image Credits

Fig. 01-06: Senthil Gurusamy.

A Fantastic Genealogy of the Printable

From Hello Sun to Always On

Prof. Dr. Ludger Hovestadt
FCL Research Module:
Simulation Platform

This text is fast, and a tad impatient. Not because it is unable to await the appearance of a foreseeable idea, nor does it indeed at all mean to formulate such an idea in the concrete. No, this text is somewhat impatient with the manner in which, in the few contexts where technology is culture-historically discussed at all, very fundamental shifts are going ignored. Or at least going excluded from discourse. Information technology is printing technology. Once conceived, it is reproducible at leisure, like a newspaper. For this reason it grows omnipresent so quickly, unlike any mechanical system. And for this reason, we notice a rhizomic net that becomes rapidly tighter across the world, in which information—whatever that may be—dashes as electromagnetical phenomena around our planet with near light-speed. A net that is the substrate not only for instabilities, but likewise for new stabilities that have increasingly begun to replace old order systems. Whereas our forbears cultivated the land under the rhythms of the sun, and along the sun's reflections built cities, today we are relinquishing more and more our familiar and secure territories and must learn to articulate what we find valuable.

HELLO SUN

Much-printed

A lot is being printed today, and fast. Newspapers, periodicals, magazines, booklets, books, folios, atlases, catalogues, albums, posters, pictures, photographs, maps, tickets. A lot is printed-on today. Paper, cardboard, synthetics, foils, fabrics, leather, glass, metals ... Linotype, intaglio, letterpress, silk-screen, stamps, ink pads, exposure, offset, Xerox, fax, laser, wax, microfilm, lithography, stereolithography ... all those colours, Pantone, CMYK ... poems, diaries, novels, manuals, instructions, drawings, sketches, drafts, constructions, diagrams, lists, compilations, collections, notes, choreographies. Even three dimensional printing today: lamps, shoes, prostheses, implants, chairs, prototypes. A lot printed, printed fast. A lot described, a lot written on. Very large, large, small, very small. Mini, micro, nano. Somewhat surprisingly perhaps: processors, memories, analogue-digital-transformers, sensors, brightness detectors, talk, movement, perception, gestures, con-tact, danger; emitters of light, sounds, images. Things are not only being described, they are actually being generated through script. Much more radically and directly than up to recently by models, layouts, drafts and constructions. Not only images have learned to walk, so has our writing. Script, analytics, reason, dialectic are being mediaized. Our articulations become real, immediate. In accordance with what we value. What they express is no longer mediated through script confirmable by sole reflection. Our thinking must reinvent its reflecting distance to the world.

The first little program one learns to write traditionally is this:

```
main( ) {  
    printf("hello world");  
}
```

Welcome to the world of articulations in which everything gets mediaized that before was written, demonstrated, and accounted for. Our particular interest is directed at the development of things, artefacts, constellations, and compartments in this world.

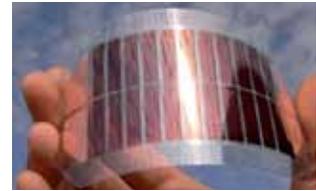


Fig. 01 Doped silicon generates electric current from the solar energy stream

Technical Articulations

The Image

For a start, let us take a simple application that clearly shows the way familiar views are being differentialized by new technical articulations. A painting has an identity. A photograph, a printed image in a magazine, is an expression of projections, of optical differences between image and object, of mechanical differences between print and image. On a flat-screen monitor, however, it is the differential that is constitutive. There are two planes: the concrete, visual plane of the printed colour pixels that may mean anything but are just pixels, and the plane of the represented shapes, texts, pictures, which do mean something but strictly speaking are nothing. Between the two planes—differing from the analytic, continuous, and the logically linguistic times—no relationship may be assumed in an unambiguous fashion on which one might depend. Monitor screens with their pixels as well as the image in its quality as differential are being double-articulated (Flusser, 1983).

But how may digital images gain stability, how may they be trusted, if no longer thanks to the shadows, the reflections of analytics, the familiar functions, figures, elements, categories? Well, through repetitions, through habits, through exercise. One pixel would not be thinkable, printable, marketable, financeable, without all the other pixels on the many appliances, in the various applications. Not without the many other related pixel technologies, not without the widespread research into semiconductor- or polymer-doping. The pixel plays on habits, habits play on pixels. The images too actualize themselves on the many monitor screens, must constantly be repeated, play out the most diverse economic or content contexts, get loaded with meanings. They form endless series of nested double-articulations that stabilize, in differentiating reiterations, into populations, and may not adequately be viewed singly, the conceptions of identities or similarities.

The Letter

The American Standard Code for Information Interchange (ASCII) was established in 1968 and prevailed in the coding of the familiar letters. 'A', for example, has the ASCII code in its first 8-bit version 01000001; 'B', 01000010; a carriage return, 00001101. Each punch on a keyboard generated, in this first version, an 8-bit sequence; such sequences then get packaged, addressed, and sent to their recipient, across the electronic networks. For the addressee to be able to read it, every letter must be treated, e.g. by rendering it on a computer screen. To that end, there are so-called fonts, such as the well-known *Times Roman*. This font interprets the code of the letter 'A', for example, into an appropriate, 16 x 16 bit pattern, which now may be read as the familiar letter 'A'. So as to make the letter better legible, one may use a higher-resolution, 16 x 16 x 4 bit pattern. One point may now be represented in various grey values, and the outlines are smoothed (anti-aliased). To increase the size of the letter, the code remains untouched, a larger bit-mask for the letter 'A' and the colouring of different points on the screen do the trick. There are comparable procedures for graphics, or images, or films. And comparable procedures exist for coding and rendering sounds and music as well.

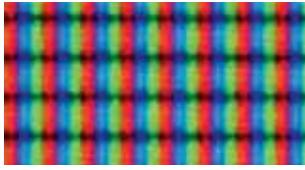


Fig. 02 Doped silicon generates electric current from the solar energy stream



Fig. 03 Enlarged screen-shot of letters, *Times* typeface, anti-aliased

Colour

An inkjet printer is equipped with a matrix of tiny kinetic semiconductors, so-called piezo-crystals that, under electric tension, change their shape and are conceived for “spitting” microscopic colour droplets, as tiny dots, onto paper.

It is then up to the so-called printer drivers to position the discontinuous colour dots so that seen from a distance, the natural and familiar continuousness of images or script emerges.

Colours are being coded and mixed according to different models. For printing, for example, the subtractive model CMYK (Cyan, Magenta, Yellow, Key [Black]) is used, and for monitor screens the additive RGB (Red, Green, Blue) model, in accordance with the colour sensitivity of the receptors of the human retina. A point of full saturation has the code 1111 or 255; of half saturation, 0111 or 127; of no saturation, 0000 or 0. Correspondingly, a red dot consists of (1111 0000 0000) or (255, 0, 0), that is to say red in full saturation, green and blue unsaturated; a medium-grey point of (0111 0111 0111) or (127,127,127); a white point of (0000 0000 0000); a black point of (1111 1111 1111), etc.

It is clear that with the availability of such printers (at a price of less than a workman’s hourly wages), which are able to colour paper with 10–20 colour dots per millimetre at will, any—as well as any future—script, any drawing, and any image may be printed in whatever combination. We do not realize that with an offset printing machine, or a Lino-type, this would, if at all, be possible only at considerable cost of handiwork. Thus, these modern processes are very successful. Barely a place in a city that is not plastered with digital print products. Street signs, nameplates, advertising, surfaces, imitations, phantasms...

Form

So as to allow free spatial movement, the code is being rendered into radial articulated systems rather than into linear axial ones. Such machines are primarily used for welding, painting, or assembling. Gramazio & Kohler, for example, use a robot for rendering a pixel-image appearance to a brick wall. A white monitor screen pixel’s code, 255 and 11111111, a medium-grey one’s 01111111, or a black one’s 00000000, may be directly translated into the rotation of a brick: 11111111 for a 90° rotation, 01111111 for 45°, and 00000000 for 0°.

Much of the current zest for bionic systems, be they straightforward bio-mimicry, or figurative analyses of biologic phenomena motivated by it, rests on simple and inexpensive reproducibility of constructs in non-Euclidean mensurational systematics, or “geometries”. There is little difference between the digital photoprint of plants and a bionic architectural construction: at most, the type of analysis may differ a little, and the



Fig. 04 Print head of an inkjet-printer with a matrix of tiny colour pumps made of piezo crystals



Fig. 05 Micro photograph of an inkjet print, rendering converts the discontinuous colour dots into familiar, continuous appearances



Fig. 06 Assembly of a wall by a robot, Gramazio & Kohler, 2008



Fig. 07 Auro, design by Zaha Hadid, 2008



Fig. 08 Diagram of boron (red) and phosphorus (green) doped silicon (black), of a photo-voltaic cell

rendering process into concrete physics may be more or less painstaking. In none of the cases of such constructions known to us was the principle of intuitive apperception abandoned. Hence the frequent interest in nature, the organic, materials, the living... A mimicry of the idea of energetic growth, hijacked into the tools of competitive struggle for attractions.

Materials

Silver is the optimal electric conductor. Copper, cheaper, is only minimally less so. Therefore it is used in the wiring-up of buildings. Due to its lower weight, aluminium is used for large overhead power cables. One distinguishes superconductive material, and conductive fluids, such as salt water, which shall however not be considered here. Crystalline structures whose conductivity depends on electric current are of particular interest.

Semiconductors conduct in specific energy bands, due to a quantum-mechanical effect dependent upon the crystalline or molecular configuration of the semiconductor. The semiconductor may, for example, act as an insulator at low current, but as a conductor at negative or higher current. It is possible to contaminate (dope) the regular structure of a semiconductor with foreign atoms. This leads to a so-called hole conduction between the energy bands. Thanks to such targeted contamination, the properties of a semiconductor may be considerably extended. As current passes through a hole conduction, a photon, which means light of some specific frequency, may be emitted. Light-emitting diodes (LED), or the new flat monitor-screens (OLED) are based on that principle, as are the lasers for reading CDs or DVDs. Or they may, with different doping, heat up or deform when current passes through the hole conduction. Or inversely emit, when the material gets warmed-up or deformed, electrons of their own, thus generating current. The above-described piezo-crystals of an inkjet-printer work according to this principle. They are also used for microphones, loudspeakers, or for micro-mechanical constructions of printer nozzles.

There exists a large library of specifically-doped semiconductors. The majority of sensors for light, brightness, images, temperature, motion, chemicals, “artificial noses”, etc., are based on specifically-doped semiconductors.

Energy

Of particular interest, in a reversal of the light-emitting-diode principle, is transformation of sunlight photons into electric current. To this end, a silicon crystal (quadruple bond) is doped with boron (triple bond) and phosphorus (quintuple bond) atoms. As a photon hits a ‘P’ atom, the surplus free ‘P’ electron gets lifted to a higher electric potential and finds temporary accommodation with a ‘B’ atom. If via a conductor, for example, a copper cable, self-insulation of the energy bands is short-circuited between the ‘B’-doped and ‘P’-doped areas of the silicon lattice, the electrons flow back to “their” ‘P’ atoms, and electrical current is generated. This is how photo-voltaic cells work.



Fig. 09 Production of doped thin-film photovoltaic cells

Simply because we specifically contaminated the crystalline structure of a particular material, it turns into a power generator as soon as we expose it to sunlight. This is fantastic—at once so simple and yet beyond our intuitive imagination. Physicists have learned to see this effect by learning how to deal with mathematics beyond analytical geometry and arithmetic, what means with numbers that are not intuitively-geometrically representable. It is the algebraic treatment of symbols that enables technical articulations within the in-determinableness of quantum physics. And it renders materials printable that generate power when exposed to sunlight. This really is novel thinking and novel articulating beneath the sun.

In labs, these effects have been known for a long time. But only now is industrial-scale production about to be mastered, whereby a major problem, interestingly, is the purity of materials and processes. But once the process works, these novel materials may be printed like newspapers. This is why the new print products, such as CD ROMs, processors, data storage, flat-screen monitors, and, well, light-emitting diodes and photovoltaic cells too, go down in price 30 per cent every year, and double their range of application every other year.

These developments have two characteristics that are unknown in the production of tangibles such as food, handicraft, or machines. For one, their price is not dependent upon their complexity or the number of constructive elements, but exclusively upon the size of the print run. Secondly, on the strength of point one, we see exponential, consistently underestimated expansion of the availability of print products. Doubling of availability every two years means that, if today about 0.5 per cent of worldwide energy demand are coverable through solar techniques, in 16 years, that means 2029, the total worldwide energy demand, and in 2037 eightfold the world's demand can be covered through solar techniques ... provided we want to. Particularly since sun's power is equivalent to 10'000 times what we need today. Year in, year out.

So much for printables. So little, what we actually articulate with it. So timorously do we cling to the familiar reflections of sunlight. Such humility within the shadow's borderlines. So much infuriation over narrowness. So little guts for stepping out of the shadow.

Always on

A simple intellectual experiment. On the dayside of the earth, we install a photovoltaic foil. Over a very long wire, it sends power to the night-side, where we connect a light-foil to it. It shines, because it is daytime on the other side. 12 hours later, it's daytime for the light-foil, which does not shine, since it's nighttime on the other side. Another 12 hours later, the foil is on again, as it's daytime at the other end ... and there is always light on this end!



Fig. 10 Doped organic material gives off light when under power



Fig. 11 Networked photovoltaic and light-emitting cells form a cultural rhizome



Fig. 12 Map of the internet - the shining planet

Just thanks to two foils and a wire lying about somewhere in the world. No more wood-piling and counting winter's days. No more asking when we wish the light to be on, but just when we want it out. Not primarily logics, but logistics. No more sureness from to following the sun.

But then, what? Whence sureness?

Prior to script, one relied upon materiality, upon the tangible, directly knowable. Things were mythical, speech only as true as the person whom one knew as speaker. In order to establish surety over distances and time, a stick was being broken in two, symbolically, so as to recover, through matching the pieces, the old sureness of the mythical things once one, or one's descendants, met again.

With the advent of phonetic script, the book replaced the sticks. We are not relying anymore upon things as such, but upon things' speech, and we check them against visibilities, against things' reflections under the sun, through a combination of geometry and logic. Certainties are being obtained through what we may hear and see within a range of, say, 30 meters. Beyond those 30 meters we cannot hear, and must greatly mistrust our seeing: the shimmering of light, the artefacts of lenses. As soon as we quit the familiar medium of the air: refractions, diffractions, distortions, before our very noses. Few sureness on the far side of narrow boundaries. When one separates, a book is being written about the reflections of things, in order to recover, through reading the book, the old reflections, on the occasion of one's, or one's descendants', next meeting. Every-thing would be in order. That could be fine.

And today, with electric writing? Now our shouting range is planetary. Within the 0.1 seconds sound takes to travel 30 meters, the electric signal takes in the whole globe. Indeed, we are, all of us, anytime, able to speak to all the others (today, via mobile telephony, to 5 out of 7 billion people anyhow), no matter where we are, and without wires. And in actual fact, some of us can talk to whomsoever is willing to listen. What are today our surenesses about whom to trust? We discover that the reflections of the shadows won't do, that they lead to totalitarianisms, that we must grant more attention to the shimmering and to refractions, that the reflections are alright for sureness within hearing range, but not for technically supported worldwide ones.

Take wine growing, in the views and rhythms under the sun that we call nature. Every day, we look upon the vineyards on the hills, and up to the weather, and we read from it what is to be done. We possess words and notions about it, and talk about what is the agenda of the following day, or the following year. The wine will turn out great if we are in optimal sync with the rhythms under the sun, with what we call nature, on the reflecting planet.

And all the wine grower may possibly harvest thanks to this nature is at best 0.2 per cent of the solar energy. And only where the ground is fertile. Territorialized.

But the same wine grower has planted photovoltaic cells next to his vineyard. They are of a different nature. Their signification for us does not follow from intuitive rhythms of the sun. They can be measured and weighed alright. And they throw a shadow. They even function in accordance with the rhythm of the sun. But it's like an open book one can't read. It too may be held in hand, weighed, and has measurable shadow outlines. But the meaning of the book cannot be apprehended in this way. Likewise, the meaning of these printed cells is not discernable on the strength of their weight, surface, colour, or smell. An open page of a book we have learned how to weigh, but not yet how to read.

For there is a crucial difference between the printed book and the printed foil. The book speaks about the reflections and continuities of things. For this, we dispose of words and notions, of well-trained certainties of geometry and logic. Foils, however, open up discontinuities, attractions, the shine of things. Few words and notions are at hand for that; we are as yet untrained in dealing with logistics and operationalities.

And all the while, through this cultural system, we are even today capable of harvesting 20 per cent of the energy radiated by the sun upon each square metre of our territories. Even in deserts and on the seas. Deterritorializedly.

A rarely experienced abundance within grasp. On the way to the shining planet.

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Colophon

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