THE WAY FORWARD

AN ISOTROPIC RADIATION OF IDEAS AND PROPOSALS

Paper on life affirming potentials of vertical farming written by

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e-paper

Prologue

Not long ago, we‘ve been asked to write an article for Austrian’s “Climate and Energy Funds”-magazine about potentials and challenges of Vertical Farming and its role for the city of the future. The article started as follows:

It‘s a hell of an exciting time we live in. There‘s so much to do. Every challenge can lead us to great opportunities. The keys are: Design. Confidence. Energy.

In times of the expansion of COVID-19, we must admit that it sounds exaggerated or irritating, perhaps cynical. But it’s the message who wants to be transported – and keys necessary to contribute to a more sensitive interaction with nature. To design, confidence and energy – in times of irreversible deceleration, contemplation should be added. At distance, we should use the time to reflect, again, what our contribution to a better future really should be. The up-mentioned article continued as follows:

The city of the future will no longer be structurally comparable to the modernist city. The design practice of the last eighty years has brought us to really great challenges that will lead to radical changes in the system in ecological, social and economic terms. This new environment allows for much greater involvement of various stakeholders from art, science and business. In addition, the fact of shaping the city of the future is an invitation for all those who have found it difficult to be an integral part of existing decision-making processes. The supply of healthy food throughout the year affects us all, especially city dwellers.

The upcoming weeks and months, supported by recommendations from scientists to narrow down the effects from the new COVID-19 virus, should be used to understand how much potential there is to really become part of a critical mass which wants to contribute to make the city of the future a more resilient, a more culture -based and - most of all - a more life-affirming environment.

Based on the current rate of global urbanization, by the year 2050 cities will harbour nearly 70 percent of humanity.[1] That translates roughly to 6.8 billion urban dwellers.[2] For nearly 90 percent of our existence, we were apparently content to wander about, seeking refuge in temporary shelters, hunting game animals, and harvesting wild fruits, grains and nuts. This all changed around 10,000 years ago when we invented farming. Thereafter, agriculture of many types rapidly spread across the globe[3], affording us the luxury of not having to hunt and gather for a living. Cities soon rose up adjacent to farmland. Animal husbandry gained in popularity much earlier that the first farms[4] but became part of the agricultural landscape when the cultivation of crops arose. Together, these two activities held the promise of providing human populations with a sustainable food supply and an animal labour force to make it work. Whole civilizations evolved from these early days of food security.

But as we steadily progressed into the modern era, urban cultures exploded into an astounding number of activities not related to growing food. As the physical area of the built environment increased to make room for these new activities, farms were forced to relocate outside the city limits. Most cities grew helter-skelter into rabbit warrens of densely packed buildings, meandering narrow streets, and a passel of bazaars, back alleys and dead-ends. Inadvertently, they became very unhealthy places in which to live, and many still are.

Today, the situation is even more exaggerated, with most farmland located hundreds to thousands of miles away from densely populated areas, creating daunting logistics challenges whose sole intent is to provide a reliable, steady flow of food items for city dwellers[5]. In addition, many countries do not have enough farmland to feed their own people and are forced to import the majority of their food from other regions of the globe. For example, most countries of the Arab Emirates import over 90 percent of their food[6], and many of them obtain most of their fresh water by distilling it from the ocean using oil or natural gas to generate steam that is then condensed and stored for use.[7]

Planning the growth and development of the built environment was within the purview of landowners, for the most part, and that is still true today. As alluded to, life was precarious for most urban inhabitants. Ensuring that their health and well-being were part of basic municipal goals and mission charters did not manifest until the advent of public health in the middle to late 1800s[8]. Commerce was the economic driver that came to define the evolving urban landscape. Chronic illnesses specific to urbanites impacted by exposure to solid and liquid industrial and municipal wastes, as well as being forced to breathe polluted air is commonplace throughout the less developed world[9], largely because maintaining a clean environment under the current configuration of centralized grids is labour and technology-intensive, and hence expensive.[10]

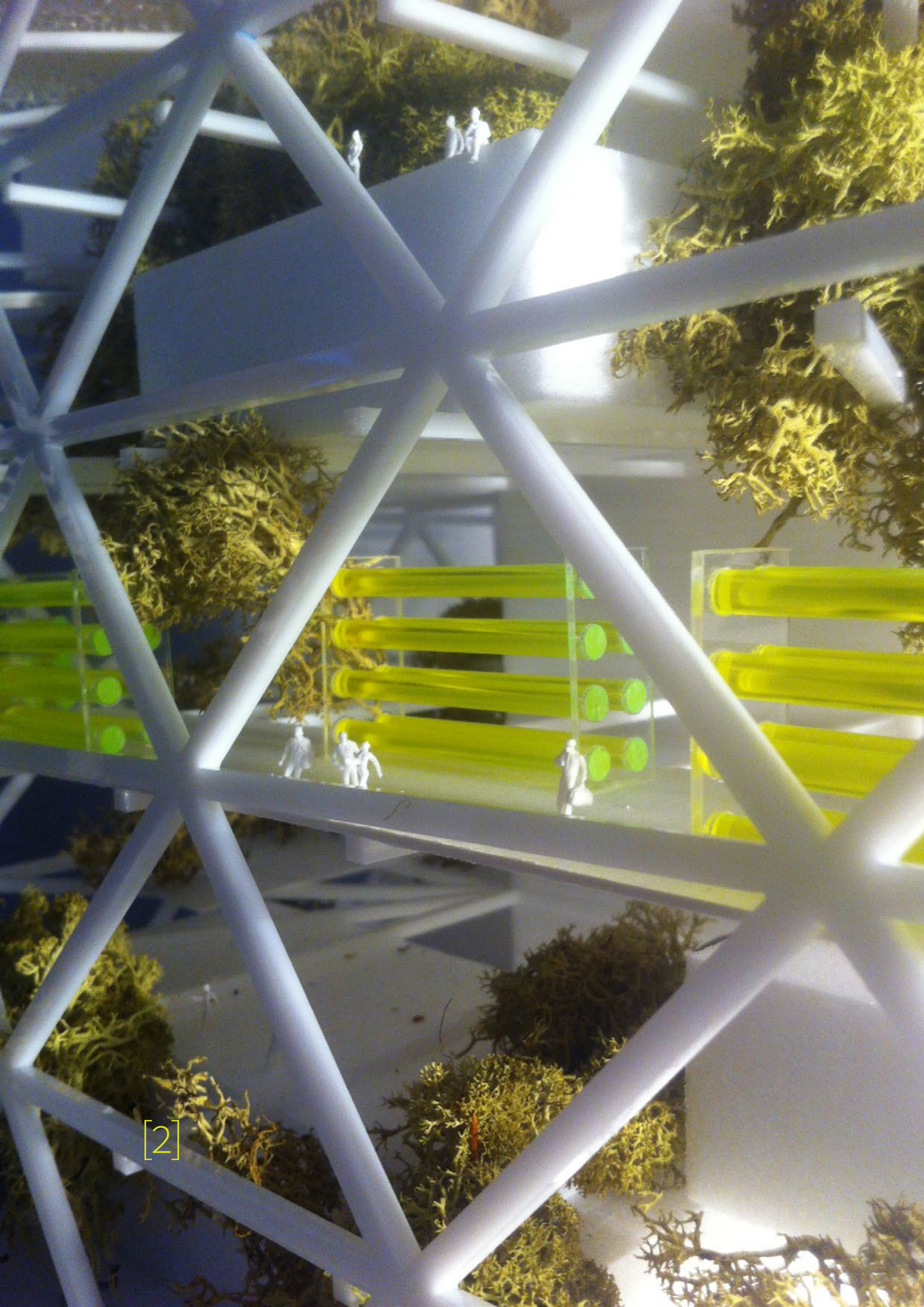
Change is what defines Earth's natural systems, and it is also true for the built environment. Typically, in most modern cities, there are few buildings that have survived from the 19th century to the present. New technologies and materials for construction coupled with social pressure from a burgeoning middle class has altered the city into a shape-shifter of glass, concrete, and steel. All one has to do is look up in order to get an idea as to the rapidity of change in today's modern city. The urban skyline throughout most of the developed world is punctuated with construction cranes and half-finished new multi-storey edifices. Two world wars have also had a significant influence on the slope of the curve defining the rate of establishment of new buildings within cities. Consider the fact that most European and Asian cities were severely affected in both armed conflicts, with some completely flattened just 80 years ago. Today, they have all recovered and most are shining examples of modernity.[11]

What is worrisome is that there is not a single modern urban centre that is completely off the energy/water/food grids (i.e., self-sufficient), no matter that we have the technologies to do so. The carbon footprint of every city, regardless of location, is out of synch with what is required in order to slow down the rate of climate change due to the generation of greenhouse gasses.[12] In the opinion of the Intergovernmental Panel on Climate Change[13], and many other organizations as well, if this trend continues for just a few more decades, it will be too late to reverse or stabilize the rate of warming.

The catastrophic collapse of Earth's terrestrial and aquatic ecosystems will harbinger our own extinction if we fail to act. Solutions are desperately needed to address this situation if cities and the 6.5 billion individuals soon to live in them are to survive into the next millennium.

This chapter is a synthesis of potential solutions, all of which are based on the concept of biomimicry of the trees that define temperate zone forests. These highly evolved life forms produce food (e.g., fruits, nuts, berries, leaves) essential to the lives of countless forest dwellers, sequester carbon in their trunks, branches and roots, harvest rainwater, and convert sunlight into chemical energy via photosynthesis.

If a city were to incorporate these same functions, using advanced technologies, into its infrastructure, then instead of being parasitic on the surrounding landscape, a city would actually function to support the recovery of damaged terrestrial and aquatic ecosystems by simply becoming self-sufficient. Most importantly, each building within that new city would be off the energy/food/water grids. Since they would be constructed using a new application of wood, cross-laminated timber, they could also become a major player in the carbon cycle by sequestering it in their actual structure, just like the trees from which they are made. The result would be a forest of skyscrapers that, seen from a functional perspective, would be the equivalent of an intact temperate zone forest. Technologies and the anticipated ecological benefits for catalysing this radical urban transformation are summarized below.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Biomimicry

Water Harvesting

Water defines life on Earth[14], and without it, nothing is possible from a biological perspective. Fresh water, a scarce resource compared to the volume of saltwater that covers 71% of Earths' surface, is an essential ingredient in the lives of the great majority of higher life forms, including all mammals. To get an idea of what our life might be like if rainwater were our only source of fresh water, one only needs to visit Bermuda to find out.[15] All 65,441 of that island's citizens depend upon rain events for all of the water they use year-round throughout their daily lives. Specially configured roofs of every building are designed to harvest rainwater. All are pure white in color so that their owners can easily see when their roof needs to be cleaned. The system works because Bermudians have no economically viable alternative. There is no ground water resource and importing bottled water is prohibitively expensive and creates the problem of what to do with the plastic bottles after they are emptied of their contents. Distilling water from sea water using fossil fuels to boil sea water is even more expensive, and using reverse osmosis devices to desalinate water has only recently seen widespread use,[16] mostly in countries that can afford the cost of equipment purchase and maintenance.

So, when water is scarce, Bermudians use less. When it rains, they resume their normal lives. Nature dictates the conditions under which they live. No one gets more water allotted to them at the expense of others. In fact, the square footage of each roof dictates how much water each house can harvest. It is a simple system that requires much attention and care, making each citizen responsible for their own water supply.

Water harvesting in other places is also the norm. The World Health Organization states:

Rainwater harvesting for domestic use and as drinking water source is becoming increasingly popular and necessary as the availability of good quality water declines. Rainwater is acknowledged as a sustainable source of water that has less impact on the environment. Households and communities have augmented or substituted their household supplies with rainwater for reasons of scarcity, salinity, quality of service and for risk substitution. Rainwater may be the sole source of water in countries like the Maldives and upland Sri Lanka, provide an alternative to arsenic-laden ground water in Bangladesh and augment inadequate urban supplies from Chennai to Kathmandu and scattered households in the mountain ridges in Bhutan.

So why not encourage rainwater harvesting for every city? In today's built environment, runoff from rain events pollutes rivers and estuaries and eventually relocates noxious chemicals and compounds associated with cities out to sea to adversely affect everything in the oceans.[17] Depending on the location, cities have the promise of securing vast quantities of fresh water if every building within their limits had the capacity to do so. As an example, the city of New York receives an annual rainfall of 45 inches or 1,143mm. That translates to a volume of 914 million cubic meters of potentially free drinkable water. As of October 2019, only three skyscrapers in that city were capable of harvesting rainwater: the Bank of America building designed by COOKFOX Architects, The Hearst Tower designed by Sir Norman Foster (captures 1.7 million gallons or 6,435 cubic meters/year), and One World Trade Center by David Childs.[18] New York City consumes some 1 billion gallons or 3.78 million cubic meters of fresh water per day.[19] Since one cubic meter of water equals 264 gallons, 914 million cubic meters of water is equivalent to 241,296,000,000 gallons of water that "cleans" the streets of Gotham on its way to the Atlantic Ocean. That figure represents a little more than half of the annual volume of fresh water (438 billion gallons or 1.65 cubic kilometres) consumed by its 8 million residents.

Instituting mandatory water harvesting in New York City could have many positive outcomes, such as allowing the estuary of the Hudson River to eventually cleanse itself, lowering or even eliminating the cost of providing drinking water to New Yorkers, and reducing or eliminating the possibility of drought-driven water shortages. Less fresh water used in the urban landscape would also enable the reservoir system of the greater metropolitan area of New York to restore stressed watershed ecosystems that are frequently sacrificed in favour of bringing a reliable source of fresh water to the city at the expense of major waterways, such as the Delaware River.[20]

Biomimicry of the temperate zone forest by urban centres with respect to conserving fresh water would undoubtedly go a long way to bring environmental justice to all those living in the built environment, regardless of economic status. In addition, enabling cities to go completely off the water grid by designing buildings that are self-sufficient removes the stress associated with resource management on the surrounding countryside. This would have major positive ecological consequences for rewilding the forests and grasslands.

There are many internet sites that feature technologies designed to harvest rainwater from a wide variety of buildings, including schools, hospitals, apartment complexes,

office buildings and even sporting arenas.[21][22][23][24]

Ironically, there are no examples of large commercial buildings that function this way. The city of Melbourne, Australia has a mandate to harvest all rainwater, purify it and store it for later use in irrigation of city properties such as grass-covered parks and trees that line the streets of the city. Flood control, preventing rain events from polluting the Yara River is another goal of that city.

In 2019, Foster and Partners announced plans to build two new skyscrapers in Shenzhen, China, both of which are designed to harvest rainwater.[25] These may well become the first examples of what lies ahead for the built environment.

In summary, when city governances, urban planners, mainstream architectural firms, and schools of architecture finally come to appreciate the true value of this essential life ingredient, then urban dwellers will reap the benefits of behaving like all the other life forms on Earth whose lives depend upon the sustained availability of fresh water.

Renewable Energy Generation

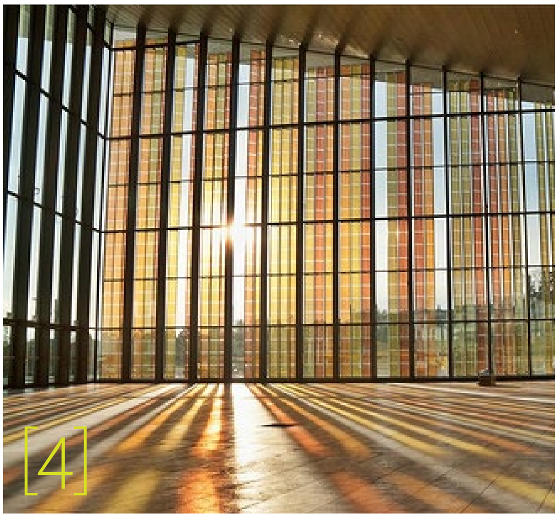
Numerous technologies exist for generating energy without the need for combusting fossil fuels or using radioactive elements in nuclear reactors: hydroelectric, geothermal, solar, wind, and wave.[26]

Photovoltaic panels are currently the most popular passive energy capture system worldwide, employed both commercially and by individual homeowners. Solar thermal facilities[27] generate significant amounts of electricity for entire cities, but use technologies that are not applicable to individual buildings. Thus solar panels appear to offer the best opportunity for enabling a single building to become independent of the urban electricity grid.[28] This technology has seen enormous increases in efficiency (i.e., percent of photons converted to electrons) in just the last 5 years.[29] By substituting perovskite in place of silicone in the solar cell wafer, the efficiency goes up from 20 percent to 24 percent. A news article in Nature[30] summarizes the situation thusly:

The first perovskite photovoltaic devices, reported in 2009, converted just 3.8% of the energy contained in sunlight into electricity. But because the crystals are so easy to make in the lab — by mixing low-cost salt solutions together to form a thin film — researchers quickly managed to improve their performance. By 2018, efficiency had soared to 24.2%, set by researchers in the United States and South Korea — close to silicon's lab record of 26.7%1. The theoretical limit for both materials is just under 30%, but typical commercial silicon panels hover at 15–17%, with the best around 22%. Unfortunately, perovskite efficiency records are set on tiny samples, smaller than 1 cm², and the performance doesn't scale up. The current record laboratory silicon cell, by comparison, measured 79 cm², and was still 26.6% efficient at 180 cm².

Specially designed photovoltaic units that also function as windows[31] are commercially available, and would allow a building to fulfil at least three of the four requirements needed to fully mimic the biological functions of a tree –carbon sequestration, rainwater harvesting, and converting sunlight into energy.

The efficiency of clear photovoltaic windows is low compared to standard solar panels, but over time, this is expected to change, making them more than acceptable for large applications, such as window replacement programs in existing buildings, and standard installation in new buildings. Over the last five years, most cities with populations exceeding 500,000 have accumulated a collection of new buildings. The great majority of them flash their presence with all-glass facades, making it possible to calculate the amount of electricity they could generate. The reality is that clear photovoltaics are still several years away from becoming practical.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Carbon Sequestration

Consensus among climate scientists confirms that there is too much carbon dioxide in our atmosphere[32] and that this compound is a major factor in eliciting rapid climate change.[33] Many of these same scientists also agree that the best (i.e., most practical and economical) way to ensure balance between the atmosphere and terrestrial ecosystems regarding the carbon cycle is to leave nature alone so that trees can do their job.[34] Prior to the advent of farming, our planet was home to some 6 trillion trees. As of 2019, there were only 3.04 trillion trees left standing.[35] Deforestation to make room for farmland eliminated nearly half of the trees on our planet. We cultivate the equivalent of some 1.84 billion hectares[36] a land mass larger than the continent of South America (1.78 billion hectares). Therein lies the problem. How can we allow 3 trillion trees to grow back without compromising our food supply? This question will be addressed in detail when urban agriculture is discussed later on in this chapter.

A new generation of environmentally conscious architects, engineers, and designers have collaborated to implement a unique configuration of wood in the construction of multi-storey buildings by using cross-laminated timber (CLT) constructions.[37] Trees serve as the raw material for the application of laminated wood products that:

» are stronger and lighter in weight than an equivalent volume of steel
» can easily be cut into any shape by CNC-technology and robotics
» allow entire floors of multi-storey buildings, cut to specifications off site, to be assembled within days on the construction site.
» buildings made from CLT can be disassembled and re-purposed without loss of materials.

This last advantage is in stark contrast to what happens to all unwanted concrete, glass, and steel structures. When these buildings are razed to the ground, none of the concrete can hardly be reused, and much of the steel must be melted down and re-cast, requiring huge amounts of energy to do so. Clear glass can be reused, but tinted glass can not.[38]

The carbon footprint of manufacturing CLT products is a fraction of that needed to smelt iron ore, then turn the pig iron into steel girders, beams and other construction materials, and ship them to a building site.[39] Using wood to construct new buildings within the city landscape has the potential for completely altering the way cities behave, reducing their dependency on the surrounding landscape so that they only need to rely on renewable resources. One significant caveat relates to the way forests are purposed. To be ecologically responsible, the CLT industry must encourage the practice of selective logging and management of forests as a renewable resource of timber, while maintaining them for maximum biodiversity.[40] Currently, the United States Forest Service oversees the management of the national forests but operates with oversight from the Department of Agriculture. The United States Forest Service states:

The overriding objective of the Forest Service forest management program is to ensure that national forests are managed in an ecologically sustainable manner. [41]

Yet many forests are treated solely as a source of wood (i.e., a crop), and are harvested by clear-cutting and re-planted with only that use in mind. The result is an almost sterile woodland environment devoid of the breadth and depth of wildlife found in unaltered portions of naturally seeded forests.[42] The newly established CLT industry has an opportunity to change that paradigm. By using only lumber selectively harvested from naturally seeded forests, wide-spread application of this technology could eventually result in slowing down the rate of climate change, thereby enabling cities to become carbon sinks[43], and at the same time allowing forests to once again become home to an abundance of wildlife. This conservative approach to forest management is already in place in many parts of the world[44], with remarkable results in encouraging wildlife to re-populate large swaths of the reforested woodland.

An excellent example of CLT construction that embraces an ecologically friendly approach can be found in the seven-storey T3 building (Timber Transit Technology), constructed in Minneapolis in 2018 in just 9 and one-half


[5]

weeks.[45] Michael Green was the architect responsible for its inception.[46] Architecture MN magazine, the official voice of the Minnesota chapter of American Institute of Architecture, described the building materials used in the T3 build:

> *The foundation, core, and ground floor are concrete, but the rest of the seven-story structure is timber, making it the largest timber building in North America. Columns and beams are glue-laminated European spruce, while the floor slabs—which also serve as ceilings for the floors below—are nail-laminated in a spruce-pine-fir mix. Much of the pine comes from trees that were downed by the mountain pine beetle.*

Another example of CLT construction is Dalston Works building in London, England[47] completed in 2019. Dalston Works is a ten storey apartment complex designed for 121 units. It weighs one tenth of a similar-sized concrete building, and because most of it was assembled off-site, Dalston Works reduced the number of deliveries of materials to the construction site by 80 percent. It is currently the world's largest CLT building. But this is likely to change, and quite soon it seems. The government of Japan has cleared the way for the construction of a 70-storey building in downtown Tokyo.[48]

As of October 2019, Wikipedia listed 55 CLT tall buildings either planned, under construction, or completed.[49] This number will undoubtedly grow, as updates on progress regarding new proposed structures become added to the table. In addition, as the many advantages of wood skyscrapers over conventional concrete, steel and glass buildings become more widely publicized, more building codes throughout the world will undoubtedly adapt to this new approach to urban construction.[50] For an extensive examination of the building codes for CLT construction see the below-mentioned website.[51]

The "turnover" rate of buildings in most modern cities is the limiting factor in estimating how long it may take to convert the majority of structures in a given metropolis to CLT-type buildings. For some cities, such as Paris, Bagdad, New Orleans, and Santa Fe, the construction of new buildings is slow, mostly due to the desire of most of them to remain historically connected to their past. In contrast, others, such as Bangkok, Shanghai, Beijing, Abu Dhabi, and New York, the rate of construction of new buildings is nothing short of spectacular.

The next 50 to 100 years will most likely see an explosion of urban construction using CLT technologies. Correlating this advance with the rate of climate change and the recovery of temperate and tropical hardwood forests will be the next big challenge for climate scientists.

Culture based

We are part of nature. We invented and developed architecture and agriculture by learning from nature. Biomimicry took ages and uncountable generations to become an intrinsic drive of human-kind.[52] This transposition though no longer was part of nature, it was the birth of culture, the true opposite of it. Shelter and agriculture enabled us to become that what we are today.

It allowed us to develop the beauty and enchanting parts of life – creating meaning and value, ethics and activities beyond hunting and gathering, from art to music, from philosophy to science. It opened up the way to division of labour where each and every human being was allowed to seek for his own and individual meaning of life.

Yet over the past six to seven decades this innate connection between humans and nature, nearly unobserved broke down, especially in the way we supply ourselves with food.[53]

Ever since agriculture became more and more structurally coupled with industry, especially the oil- and armament's industries, agricultural production has not only completely changed in practice and scale, but also in its energy consumption patterns. From the Neolithic Revolution to the Green Revolution, the only energy sources for food production were human labour and direct solar radiation, which was then supplemented increasingly by the use of electricity and, above all, by fossil fuels.[54]

Agricultural production is becoming ever more energy-intensive, if not altogether dependent on cheap and seemingly abundant oil and gas. It is becoming a widespread concern that the reliance of the global food system on fossil fuel increases drastically. In fact, there is an intrinsic factor of energy consumption in conventional food production that transcends the structural coupling of the oil- and the food industries. At the present time, the food system (food sector), accounts for one third of the world's energy consumption, 25 % of this within the farm gate.

Within the production entity of the Vertical Farm a significant reduction in hydrocarbon energy and CO_2-emissions can be monitored already. Greater potential can be assumed by scaling up this practice. Substitution of natural sunlight with electrical power and heating demand for year-round crop production however, might well increase energy demand in urban agglomerations. Therefore, careful and precise questions have to be answered.

Where do we produce what and how, and especially when?

If the UN is right and we really will be 10 billion people, and this very soon, then we will have to assign an additional area comparable to Australia for food production. The question of where we will find it is easily answered: If you look at the actual biocapacity of the Earth, which is suitable for food production, then there is a clear answer: under the treetops of centuries-old forests. Slash-and-burn practice is the order of the day, and as we are writing this article, that practice is an ongoing process at a shocking speed. And it happens before our eyes.

On average, even today, a citizen of the earth occupies about 1,800 m^2 of land for his year-round daily food supply - we are talking about cultivation area and not about the ecological food footprint.[55] This number is rapidly increasing, mainly due to socio-demographic changes – not only in China and India. In contrast, the impervious surface area (ISA) worldwide per capita is only 67 m^2. Of course, cities are also growing, but not at the same rate as agricultural land. At present, one can apply a rule of thumb: Every square meter of urban growth triggers 26 m^2 of growth for agricultural land.

At the same time, however, the earth's biocapacity is shrinking. On the one hand due to climate change, which leads to desertification and extreme weather conditions, on the other hand owing to the practice of conventional agriculture.[56] The promise of the green revolution, its unneglectable positive results in terms of yield of the past, now turn out to be short-term achievements. Defined in terms of plant physiology, one could almost claim that the peak of the sigmoid growth curve has been reached, mathematically: We are now on the beginning of the decline of the Bezier curve in terms of energy harvest (kcal) per hectare agricultural land.

It is tiring for everyone in charge to implement solutions to mitigate the consequences of this practice as these findings are not new. Since 1995, we have been meeting at annual climate conferences and observing how CO_2-emissions are increasing continuously.

The core focus on food production is missing or does not receive the importance that should be ascribed to it.

However, the findings or the indications of necessary changes in our economic practice in general go back much further than that: here we need only mention the Brundtland Report[57] from 1987, numerous publications from the scientific community of the 1960s and 1970s, and one of the most important anchors of knowledge in this context: the Club of Rome funded in 1968 with its manifest „The Limits to Growth“[58], published four years later.

The situation today is more than explosive. News of crop failures due to extreme weather conditions such as heavy rain, drought, hail, frost, etc. are commonplace and are no longer reduced to individual geographical locations: They are a global phenomenon. Our own calculations of the necessary land development, which is mentioned above, namely to develop approx. 139,000 km^2 do not even take into account the parallel loss of already developed and active production areas which have to be compensated, too.

Let's revisit the numbers: approx. 1,800 m^2 versus ca. 67 m^2.

» Can we find a really good, plausible reason why we shouldn‘t use all our creativity, investment capacities and research activities to add a coordinate- the z-axis- in our thinking?

» How will our view of the future of agriculture change if we no longer think in terms of harvested energy (kcal) per square meter, but per cubic meter?

» And what is to be said against using all the resources required above - creativity, investment capacity and research activity - to try to develop (not to invent!) and implement production methods exactly where the earth‘s surface is already sealed, namely in cities?

It is worth ascertaining how much unused space we have in every city, beyond residential and office buildings. We're talking about thousands and thousands of square meters of rooftops of supermarkets, shopping centres and industrial estates. In addition to the roofs, the city also exists as façade areas. These can also be activated for food production, although only to a more limited extent, but nevertheless.

Furthermore, the question must be asked how much unused cubature in a city can be activated for food production.

As the royal discipline, the great throw of an overall systemic view[59]: the implosion of the global food value chain, from production of nutrients to the production, temporary storage, harvesting, washing, processing, packaging, direct marketing and sales: the development of economically sustainable innovative function- and space programmes for a new building typology[60]: the vertical farm.

Since 2009, we have seen strong growth in various controlled environment agriculture (CEA) units from America to England and Singapore to Japan. We are somewhat under pressure to define the term Vertical Farm.[61] Many CEA units are now defined as vertical farms, which makes the political debate on vertical farming difficult. In most cases, it is simply a matter of verticalising already known greenhouse cultivation- and production methods. Furthermore, as the fastest growing business models are found in the area of plant factories, the debate is made more difficult by the fact that these operate with the complete substitution of natural parameters, including the 100 % substitution of daylight by photosynthetically active radiation through LED lights with all the consequences in related to energy consumption.

We see two fundamental barriers to the speed of development here: high energy consumption and reduction to a small structural element of the food value chain: production. Undisputable advantages by plant factories are the acquired know-how within the past 11 years, and every production entity can be integrated into a more complex function- and space programme representing every single structural element of the global food supply chain – as an implosion of it – within a building or a building block.

We do see in the results of our own research and other publications the potential that a holistic view on vertical farming offers the opportunity to also radically reduce energy consumption (operative) through positive externalities.

A look into the past can also support us in this way, in the development and implementation of vertical farms.

Already at the beginning of the sixties a forgotten prototype was built not far away from Vienna, Austria: A glass tower from the year 1963. 11 meters in height. Inside it there was a paternoster-system, with a „few plants protruding from its receptacles“. This type of building, which had never been seen before, attracted so much attention that it was further developed in 1964 to a height of 44 m and was presented at the opening of one of the largest public parks at the “Wiener Internationale Gartenschau”, The WIG 1974 Expo Show: We are talking about the Ruthner Tower, the oldest vertical farm worldwide.[62] Although only in operation for a short time and then dismantled again, it is a great sign of the visionary thoughts of the inventor Othmar Ruthner.

Discussions with Oswald Ruthner, the pioneer‘s son, CEO and managing director, reveal three points that can help us further in the development of vertical farms:

» Lessons from the past why the project did not scale up

» To make visible which findings in science, research and technology since then can make their implementation possible today

» Lessons learned include, for the first time, the failure of the business model, since, as in many Western countries since the 1960s, food prices imploded.

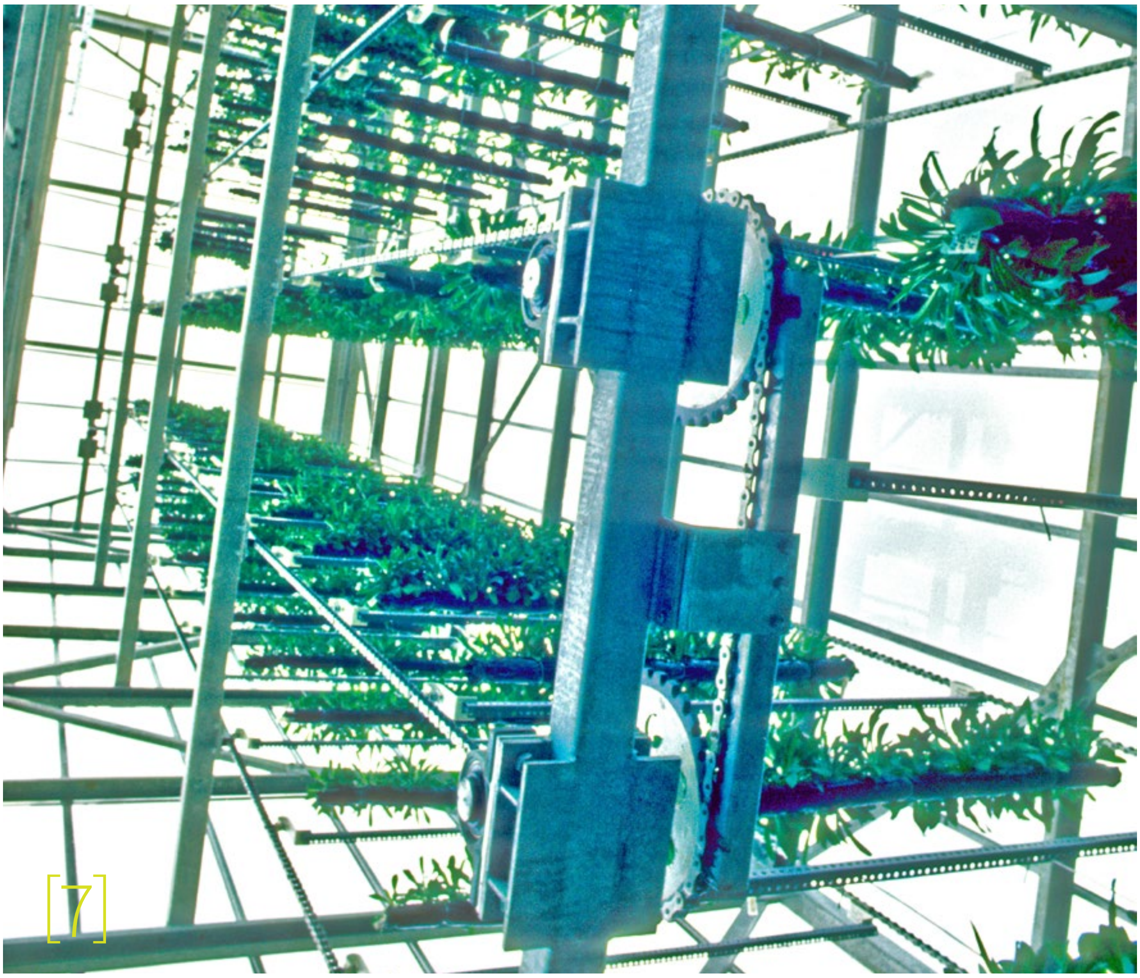
A problem – from farmers’ and producers‘ perspective - we are still struggling with today. We will see whether the COVID-19 crisis will leave the food value chain untouched, or whether changes will occur here too that we cannot yet estimate today. It is, of course, tough competition (which it should not be) that every company in the CEA sector must rely on cost transparency to be successful, while producers on conventional farms can rely on additional cash flows. The only thing worth mentioning here is the subsidy policy. Furthermore, to formulate this here as a provocative thesis, we have to acknowledge that food production with vertical farms is the cheapest option of all cultivation and production units. For the following reasons:

After all, we pay for our food products not only with the money we hand over to the supermarket or wholesale trade. We pay a large part of our daily bread through our taxes, which are added to the subsidies and grants. We also pay for it through environmental destruction, slash-and-burn practices for build up new land for agriculture, the consequences of climate change and the practice of conventional agriculture. Lastly, we pay a contribution through the development aid. Part of this is spent to cover the costs of (internal) migration, which is caused by the fact that many Western countries are turning agricultural states into export countries.

To get back to CEA producers: Independently of this, we see that it is possible to develop innovative business models and thus make a living from urban agriculture. Particularly during the quarantine period in these weeks, imposed by the spread of the COVID-19 virus, a strong increase in sales of urban vertical farmers can be observed. Direct marketing is experiencing an important boost during this period. The recognition that as a producer and consumer it is possible to strengthen local socio-economic networks is an important driver in this debate. Trust, transparency and relationship are intangible qualities that will strengthen this and future business models.

In contrast, to get to the second point, the state of research and the state of science: A second Ruthnerturm, from the year 1974, still standing as a ruin in the south of Vienna. It was erected in those years when the first publications of K.J. McCree[63] appeared. These approached for the first time the knowledge of how photosynthesis works, which parts of the light tower it influences. The principle of trial and error in the practice of the company Ruthner IP was a maxim that can only be attributed to a true pioneering spirit. Sodium vapour lamps, high pressure sodium lamps, mercury vapour lamps were used. Each one had an energy consumption from 800 to 1,000 W, of which most of the power wasn't "transformed" into light, but heat. This resulted in water stress or burning of the plants. In addition, the building service technology had to be continuously reshaped: overheating in summer and the heating requirements in the coldest weeks were the biggest challenge. The building envelope consisted of single glazing with a U-value of approximately 5.88 W/m². In the end, the control and regulation technology covered only a few processes, but the „computer's" dimension was approx. 2 cubic meters in size.

Today, we already know the required daylight integral (DLI)[64] [65] of an ever larger group of cultivars, we have highly efficient LED lamps with an ever better watt-to-watt conversion, we know about the sigmoid growth curve, about water- and nutrient requirements - in short, from a plant physiological point of view, the knowledge has grown exponentially over the last decades. Today, greenhouse technology and building service engineering, coupled with energy simulation technology, give us the opportunity to develop systems with the lowest mechanical and energetic expenditure, which is justifiable from an ecological perspective. At the last, and this can only be briefly hinted at here: The state of the art in control and regulation technology, sensor technology, monitoring etc. up to - if one wants - full automation and robotics (agriculture 4.0) is more than sufficient to develop and successfully operate new building typologies producing food on demand.



We have learned from nature. But food production is a cultural achievement. We should be proud of the achievements of the last 11,000 years, especially in the last century. Today we harvest six times more kcal/ha, the agricultural area has only doubled in the 20th century, whereas the world population has tripled. But we must also acknowledge that the price we pay for this is too high. In addition to increasing energy input by 8,500%[66], we have destroyed and continue to destroy natural areas, we are reducing the soil capacity mentioned above, kcal/ha are decreasing again, and global agriculture is completely dependent on cheap oil.[67]

Four hundred years of experience in greenhouse crop production are to be shown. We know about the challenges of the future in food supply. We should now join forces and focus quickly on how we can ensure food security for future generations - an important pillar, an additional structural element in the whole of cultivation and production methods is the vertical farm.

Lastly, we have to acknowledge, that one m^2 of built-up land, on where a vertical farm is established, can compensate between 50 to 120 m^2 of agricultural land – year-round – delivering the same amount of food.[68] We have to ultimately raise the debate on what exactly the price of one m^2 of nature is, and how we can add value to it, increase the debate of payment for ecosystem services and getting honest and serious about the challenges we're facing. Vertical farming is not in competition with conventional farming. Many changes have to happen there, too. And it already is in the centre of a necessary transition process. Besides that, an additional structural element in food production might be an important foundation to supply 70 to 80% of urban dwellers in 2075, hopefully living in a resilient city we have to design today.

We have to design and implement them wisely. The biggest energy consumption is related to the embodied energy, the question on construction and building materials have to be addressed.

But not always a new building has to be designed, an analytical view on already existing urban spaces will highlight enough of unused spaces, materialized energy ready to use so to say. The knowledge on the needed growing condition for specific food items will lead to an impressive feeling the moment when one recognizes how much unused potential spaces around us are capable to extend our food supply system.

We'll then see the market potential for supermarkets by activating unused spaces on flat roofs or parking lots, market potential for wholesale traders by producing on their own site, market potentials for urban developers by refurbishing shopping malls, refurbishment of buildings where remarkable investment costs are awaiting for its energetic restorations, green building certificate standards expanded with food production categories, green facades[69], growing potentials for greenhouse areas[70] in cities and edible parks.


[8]

Life affirming

Deceleration and Contemplation

Let's face the facts: We're in constant exponential growth, our cultures are still based on our modernistic conviction that economic growth is a law of nature. On this point I have to recommend to intensify this debate elsewhere, together we now have to accept and to admit that within the next decades nothing will change fundamentally: We will rapidly continue our practices in conventional agriculture, we will continue to destroy vast parts of nature on this planet. But together - we - should combine our forces to slow down this process, to be successful in our business, our scientific activities, in the way we communicate and disseminate and lastly, with our direct or indirect political activities.

Together – the greenhouse industry, businesses involved in urban food production, plant factory operators, researchers and students – we must highlight the potential of our activities – potential related to meeting already addressed global sustainable development goals. We have to highlight them to support decision-makers, politicians and wider thinking investors to intensify their activities and actions to transform agendas into action plans.

Especially politicians on a local level have it easier to turn on a green light for realization projects all around urban vertical farming if we support them adequately. Support is necessary especially on that political level (in terms of hierarchy) to make these political leaders successful. And, a politician is successful, when he's getting re-elected. And here's the good news: We're in the middle of a paradigm – shift: Consumers want transparency within the food sector. Consumers know what they want to have on their plate, not just in terms of quality, but they also raise ethical framework conditions by saying the way we exploit people within the production – system (from the farmer to his harvest hands). All together we have to get explicit, raise our voice, and communicate our next steps into the next era of food supply.

Enlightenment

We're conscious of the challenges, but we don't have to invent anything. We have the knowledge, technology, human resources, in addition now the biggest economic-growth recovery package is awaiting in several countries to be set up. Lastly, area as already highlighted above is limited, but space is not. Combining knowledge, experience, know-how and funding now and today is the biggest chance to make this paradigm shift possible. We can make cities resilient by activating spaces for daily year-round fresh and healthy food supply.

In our communication, again, we have to intensify the positive externalities of urban vertical farming. Especially when it comes to representable interconnections within the urban food supply chain which are strengthening socio-economic networks. Feedback on customer relationships from urban farmers and plant factory operators during the COVID-19-lockdown is more than just encouraging. Urban farmers, next to their actual work, are an unwinding structural element from a psychological perspective. And lastly, there's no urban farmer I heard where its turnover hasn't increased.

New communities are constantly emerging. This is a permanent process. But what's fantastic on that, when it comes to new socio-economic business models. The „future farm" or „Zukunftshof",[71] a project in Vienna the vertical farm institute is privileged to support and advise is the physical representation of an initial idea which led to a grass-root movement which made it easy to get political support for a refurbishment action of a city block of around 25,000 m^3 from the late 19th century. What's the task? Keeping the building, preserving the embodied energy and transform each and every m^3 of unused space into a food production-related entity.

To find people who want to be involved is proving all but difficult. This project already created a new community with constant growth. The interesting part of it: The idea, the vision and the mission bring people together with different backgrounds – from social to education, from organic farmers to vertical farmers, from hands-on people to scientists, from neighbours to universities.

This project like any other, again for the transformation process of our cities, can integrate the idea of circular economy, measuring and optimizing material- and energy flows. The implosion of the food supply chain within one building or a building block radically increases the understanding on what actually circular economy principles are, because of a specifically drawn line which marks the system borders. An intelligent energy design, based on questions such as level of comfort for people and optimal growing conditions for plants, fish, insects, mushrooms etc., guarantee long-term sustainable operation processes. Expertise – also already existing – in water management, waste management and energy storage – is key to it.

Acceleration

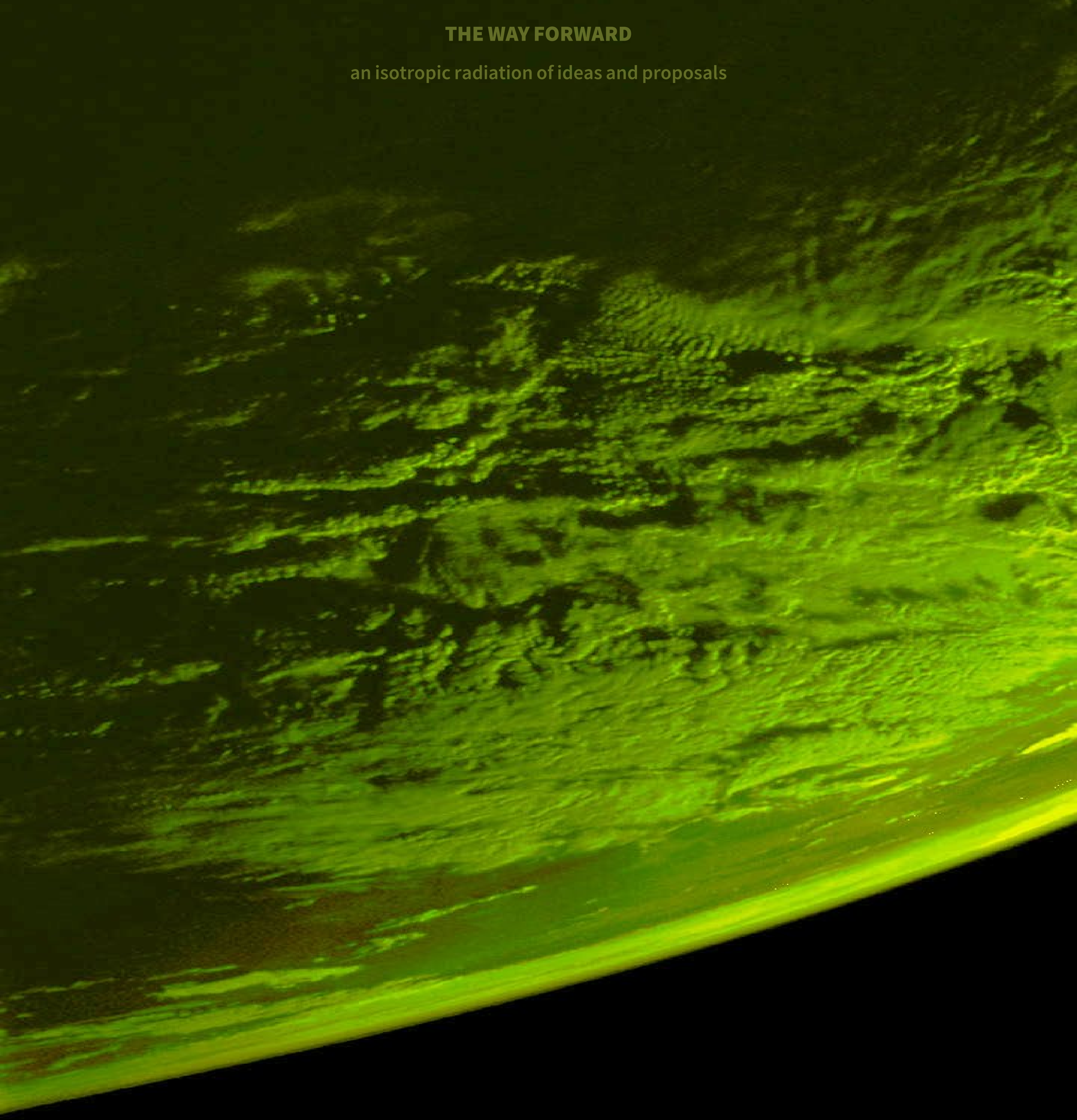
In the authors‘ opinion, scaling up urban vertical farms, expanding this idea into refurbishment projects, activating unused spaces within the city limits are the biggest drivers for innovation. Exactly these kinds of projects which produce obvious and measurable added value for communities, for the urban environment, the (reinvented) public space attract co-creators and partners – people which want to contribute to a more resilient future – acknowledging intergenerational justice just as the increase in giving nature and culture the adequate value.

It's too late to be a pessimist, and it's not necessary to be one. Change happens and it can be observed all around the world. But facing two counteracting forces: There's still reactionary energy out there from the drivers of the last century. And climate change, together with the destruction of natural land is proceeding much faster than one would imagine. This is hard talk, but closer to recent reality than one would like.

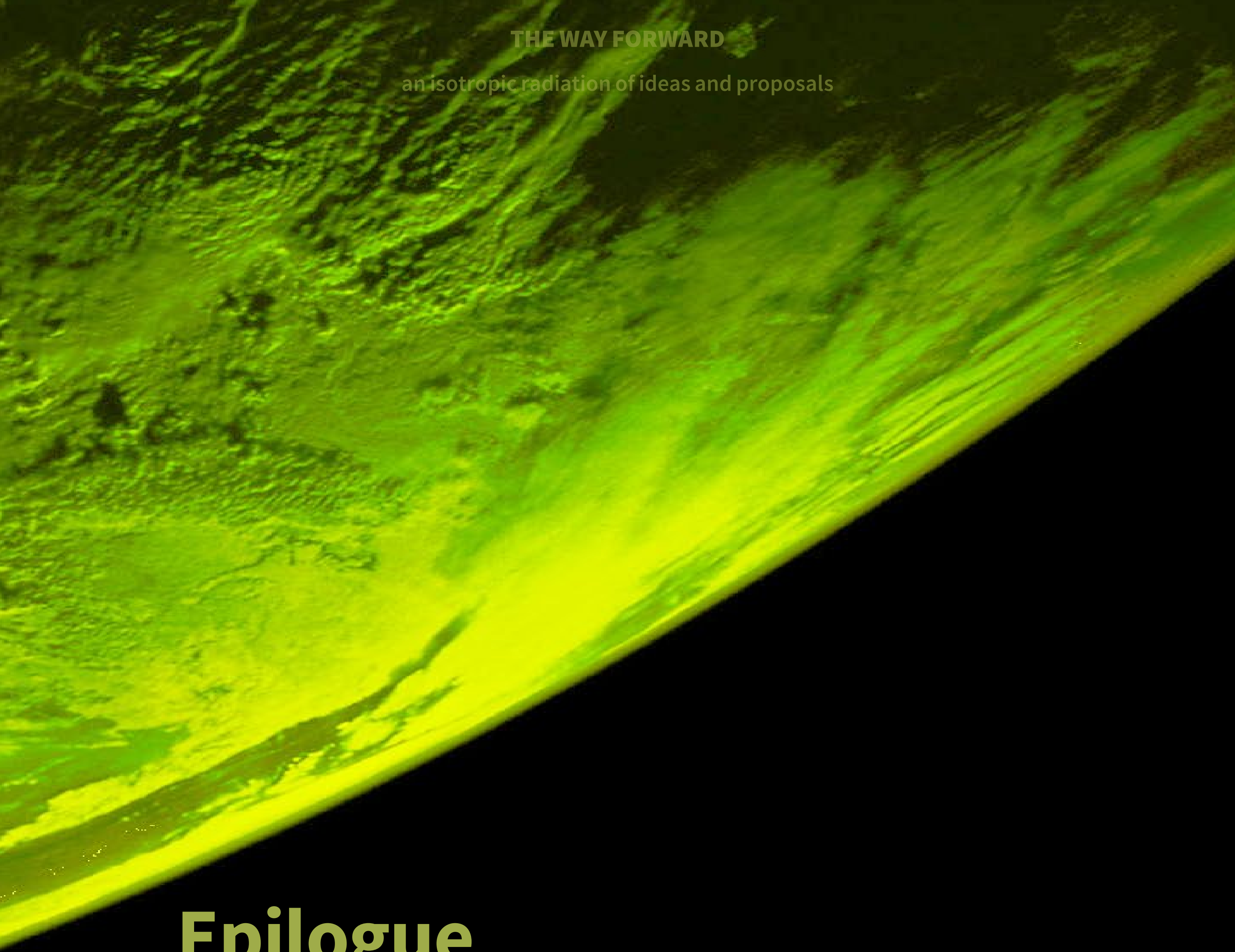
In conclusion, one can state that in our period of unneglectable challenges we have to be conscious about our patterns of thinking which sometimes lead us to reflex reactions such as looking for all-in-one-solutions (as in German one would say the "egg-laying, milk-bearing woolly sow") which the vertical farm certainly is not. But it is an important icon if implemented correctly. It is an object embodying or transporting the potential to oversee material- and energy flows of a complex system with clearly defined system borders.

By accepting its complexity, the analytical process starts leading to solutions to understand natural processes and transform them into technological solutions – biomimicry at its best. And this precisely defined system border of the building itself – of the vertical farm – leads in a metaphorical sense the sensitivity to understand that in nature everything is linked. Science or the need for human-kind to understand its environment – must define narrow system borders for raising precise research questions to find the right answers.

However, for the vertical farm to make significant contributions to the resilient city and mitigating climate change, it is a result of brilliant planners, contributors and developers across systems by applying already retrievable knowledge. In terms of design, the stronger this icon is, the more it is an enabler or facilitator to attract people to develop a new building typology for the 21st century – a building typology which accepts the limits to growth, acknowledges scientific evidence, the intrinsic human drive for change to the better, the appreciation of life.



[9]



Epilogue

It is science which answers the right questions, it is philosophy to interpret them adequately from ethical perspectives. It is art to express and architecture to materialize thoughts.

The vertical farm is an icon for the appreciation of life and nature, acknowledging the massive resource- and land use a single human being encounters for to improve or maintain its quality of life. As an icon, it creates identification potential to urban citizens, it brings, beyond food, transparency back into the food sector – in the heart of the city.

By accepting this, we enable political actions, we will use the upcoming recovery packages adequately, the urban community will be involved in process, development and operations, and our next generations experience relief by not only getting depressed by the feeling in standing in front of unsolvable problems but being part of this transformation process which „finally will lead us to a peaceful coexistence between humankind to the rest of nature“.[72]

Food production will be part of daily urban life again.

Endnotes

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List of figures

„The Vertical Farm – a building typology which accepts the limits to growth, acknowledges scientific evidence, the intrinsic human drive for change to the better, the appreciation of life.“

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