Will the Covid-19 Pandemic Transform Our Urban Habitat?  
A Microalgae Photobioreactors Labyrinth-Garden as an answer for The Post-Covid Sustainable City

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Abstract
The epidemics of the first half of the 19th century made sanitation an essential point in the urban life. It laid the way for a city based on sunlight, ventilation and an urban planning of straight-lined, wide street and green areas. Until the beginning of 2020 we have lived in the belief that this urban model protected us. However, there were already many indications that the city was not capable of giving a satisfactory answer to the parameters of the 21st century, such as pollution, the heat island effect and the excessive consumption of energy and resources. Now, the coronavirus COVID-19, has put a stop to the city movement and with it, to the pollution it involves, revealing the level of contamination to which we were exposed. Therefore, it has become a priority to minimize energy consumption, energy dependence and pollution to improve the health and quality of life of its citizens. As answers to these demands, buildings with living organisms, such as microalgae, make the city a sustainable and Self-Sufficient environment. Giving an answer to the problem above, the design of the Park-Labyrinth proposes the installation of an intensive cultivation of microalgae that not only helps reduce CO2 emissions, transforming it into a product that generates interest, but also generates benefits to society in terms of recreation, energy production, reduction of polluting gases and use of space.

Key Words: Covid-19, self-sufficient city, pollution, CO2, microalgae, photobioreactors, labyrinth

1. Will the Covid-19 Pandemic Transform Our Urban Habitat?
The epidemics of the first half of the 19th century, especially that of cholera, gave rise to a society in which sanitation became essential. Through research, doctors and scientists agreed that the unsanitary conditions in which a large part of the population lived were, together with malnutrition, a direct cause of disease. Sanitation laid the way for a new model of city that has prevailed ever since. Urban planning, healthier and sanitary, was based on sunlight and ventilation. It resulted in straight-lined, wide streets as opposed to labyrinthine and narrow alleys. Water infrastructures were improved. Green spaces - wooded boulevards, public parks- were integrated. Food sale was controlled through new markets, and harmful industries, slaughterhouses, cemeteries, etc. were relocated out of the city.

The basis of the contemporary city is the transformation required by the impact on public health of the nineteenth-century epidemics. Urban planning legislation, as we know and apply it today, is the direct spawn of those circumstances. Until the beginning of 2020 we have lived in the belief that this urban model protected us from the evils that we already knew. And the unstoppable growth of building construction on the planet has been a reaction to the epidemics of the XIX. However, there were already many indications that the city was not capable of giving a satisfactory answer to the parameters of the
21st century. If two centuries ago it was foul water quality that made the city unhealthy, today it is foul air quality that produces respiratory diseases amongst the urban population. Issues such as pollution, the heat island effect and the excessive consumption of energy and resources made us foresee the need for a radical change in the urban model. This sanitary city has long been threatened and surpassed by other environmental factors.

If up until a few months ago the bustle of people walking the streets, the traffic jams filling the city with noise and pollution, CO2 and NO2 particles traveling through the air, etc. constituted the world urban invariant, today we find that pedestrians and cars have disappeared, and with them, part of the harmful particles. In exchange, the flow of a new agent, the coronavirus COVID-19, has appeared, and data and telecommunication systems have increased. These have become the new social spaces.

Faced with this situation, so dramatic due to the scale and speed of events, and in view of the new work and personal habits that the population has been facing, we are left to ask ourselves: Are we at the gates of a change in the urban paradigm?

The current confinement situation has exposed the level of contamination to which we were exposed. In many major cities, such as New Delhi in India or Lima in Peru, thanks to the imposed quarantine, air quality was recovered to a point that had not been seen in at least 20 years. Stopping human production and transportation activities for a period of time meant that city residents recognize the unhealthy air quality in which they live.

From an urban point of view and outside analysis of politicians and strategists, cities are large consumers of energy, producers of CO2 and environmental pollution. Each country should have among its main strategic objectives to minimize energy consumption, energy dependence and pollution to improve the health and quality of life of its citizens. The proposal that we present here is based on the most abundant living organisms in nature, algae, to obtain clean energy and to reduce urban pollution, so harmful to health.

2. Building with Living Organisms (Microalgae) for a Sustainable and Self-Sufficient City

Cities are the main centers of energy dissipation and CO2 emission. Therefore, alternatives are needed, such as the one presented here, that contribute to intelligent intervention in urban fabrics. The young technology of algae brought to architecture transforms the city of consumer into producer of energy factor in situ and city "CO2 sink", plus other advantages.

The city presents various opportunities scenarios for integrating bio-energy production and different products obtained from algae growth. We present, in this project, the development of a highly integrated and innovative construction system, that originates of the use of living organisms, such as microalgae, in a "technological garden" that reinterprets the Labyrinth for the production of bio-energy by absorbing sunlight and converting it through photosynthesis into, biomass, biogas, fertilizers and other products. For the absorption of CO2, allowing circulation of fluids that incorporates algae, through these surfaces and creating new types of architectural photo-bioreactors. [3]

The importance of algae lies in its abundance on the planet, and its ability to fix the earth’s carbon dioxide and release large quantities of oxygen into the biosphere. Microalgae are microorganisms that are, on the one hand, autotrophic, i.e., they collect inorganic substances, such as carbon, hydrogen, oxygen, nitrogen and phosphate. Also, they produce organic substances, such as sugars, fats, proteins, nucleic acids, enzymes, vitamins and oxygen. This means they are the raw material for manufacturing food for humans and animals; as well as medicines, biomass, biofertilizers, etc. (Figure 1). On the other hand, they are also heterotrophic organisms, or in other words, they incorporate organic matter, thereby acting as purifying agents on pollutants.
Their ability to survive in different environments, and even in very extreme environments, means they have enormous ecological value. Its main sources of nutrition are sunlight and carbon dioxide. These organisms are composed of carbohydrates, proteins and lipids, and medicines and antibiotics, pigments, steroids and other products can be obtained from them. This is in addition to its abundant biomass, which if treated correctly, can be used as a base for clean energy. Another of their major applications is for bio-fertilizers, thereby reducing the impact of chemical fertilizers on the energy consumed worldwide, and the NO2 emissions resulting from nitrogen fertilizers.

For this reason, the importance of microalgae biotechnology has increased in recent decades. Various avenues that will enable it to reach productive and profitable maturity are being explored, such as the proposal presented, that is an implementation of an intensive algae crop in the urban environment by reinterpreting the labyrinth concept.

3. Reinterpreting the Labyrinth: Project Description

The presence of labyrinths in the history of mankind dates back to the Neolithic Period, in different parts of the world. Representations of the labyrinth occurred in pictographic forms such as mandalas in India or archaic petroglyphs, Amerindian basketwork designs, and paintings or drawings from around the world. [2]

The first reported labyrinth was a two-story building in Egypt, described by the Greek historian Herodotus. The labyrinth is an archetype that has been used as a symbol of multiple meanings related to the human mind and the winding path of one’s own destiny. In the common background is the best-known historical representation of the labyrinth: the Cretan structure in the myth of Ariadne, Theseus and the Minotaur. [2]

However, all these theories agree that the sinuous shape is typical of labyrinths and can be equated to a fractal-like geometry that folds back on itself. This expression can be taken to the limit, as is the case of the Peano’s curve, where a surface limited to the linear dimension can become infinite and cover a superficial element until it is defined in a one-dimensional way.

The modernization of the historical labyrinth, understood now as a technological fractal that multiplies its dimension in a limited space, allows to incorporate a true “Urban Green Energy Factory” into the urban garden. The low effectiveness of the algae is thus compensated by the increase in the length of the pipes or the area of the surface of the diverse kinds of photo-bioreactors.
Figure 2. Characteristics of the set used to create the labyrinth.

Giving an answer to the problem above, the design of the Park-Labyrinth proposes the installation of an intensive cultivation of microalgae, using as a base the reinterpretation of the labyrinth, based on the Lindenmayer System. This logical-mathematical structure is a set of rules used to model the growth process of plants. One of the characteristics for which this system was chosen is the self-referencing of the rules, which leads to self-similarity. As the recursion level increases, the shape grows on itself and becomes more complex, like a parametric system. In this case, growth rules were applied to generate a path based on the division of a line on itself to cover the greatest amount of path for a given rectangle. (Figure 2)

The research involves the design of a garden-labyrinth made of different models of urban photobioreactors with their technological apparatus, and the calculation of the capture volume, as well as the calculation of the captured CO$_2$ for the benefit of urban air quality (Figure 3). The biomass obtained is transformed into bioenergy, through its generation of biogas and by cogeneration into electricity, and into 100% biofertilizers, thus avoiding the energy consumption of nitrates. As an added value, we indicate that the energy produced by the algae is "in situ", being able to supply energy to nearby areas of the city. The research presents tables with equivalences for supplying urban neighborhoods.

The project is committed to the photosynthetic capacity of microalgae for the bio fixation of harmful emissions. The assimilation of CO$_2$ is the process with the highest energy consumption in photosynthesis, with the production of microalgae being the most promising since they achieve yields close to 100 Tn of biomass / Ha per year and photosynthetic efficiencies of 2.5%. Comparing them with the biomass yields of the forests that oscillate between 10 and 40 Tn of biomass / Ha per year and photosynthetic efficiencies between 0.25 and 1%, the microalgae have 60% more efficiency [1].
4. Results and Data
First of all, the volume of the proposed photobioreactors must be determined. In the present investigation, 4 different types were proposed with variations in their forms and structures. The only significant variation between them is based on the type of harvest: a continuous harvest is proposed for a small part of the photobioreactors. Which constitute the intensive production that supplies the base volume of algae to the rest of the park; and a semi-continuous crop that is used in the climbing phase since it has a lower production but its application is cheaper, thus promoting its scaling. (Figure 4) The project has 28,603.19ml of photobioreactors that contain a total of 8,094,145 L, of which 614,387L correspond to a continuous culture. The entire cultivation has 17.85 Ha (No. of hectares) that incorporate all the structures necessary for the operation of the labyrinth as a landscape element of the city and as an intensive cultivation of microalgae. (Figure 5)
Figure 5. Prototype of semi-continuous culture photobioreactor and arrangement of modules for confronmación of labyrinth.

Second, to make the calculations of biomass production, CO₂ fixation rate, and energy efficiency, the type or strain of microalgae to be used must be determined. The type of microalgae chosen must be a native of the implantation site as it will be adapted to the environmental conditions of the place, such as light irradiation and temperature. As an example, the calculations of the present investigation were made for a specific area in the city of Madrid, with a type of microalgae strain that adequately manages the climatic conditions of the city. In the case of the Senedesmus Vacuilstus strain (strain chosen for its high production at the temperature variation of Madrid), the optimum temperature for a medium-high biomass productivity ranges between 15 °C and 35 °C [5]. According to these data, the plant can only operate in the months of March to November in continuous intervals.

5. Biomass productivity
According to the aforementioned conditions, for the calculation made by García Cubero, R. (2014), the optimal productivity achieved by studying a crop in a reactor similar to the one planned was used. This value is 0.13 grams per liter per day (g l-1 d-1), where the collection is made every 3 days, extracting a volume of 65%. According to these data, it is proposed to collect a max. 25% of the crop daily. [5]

To calculate biomass productivity, the number of grams of biomass produced per liter of solution in a day is computed. Based on a series of calculations, it was determined that the biomass productivity of Senedesmus Vacuolatus is 0.15g per liter per day in a semi-continuous harvest, which is the case of vertical photobioreactors (used in the climbing phase) and of 0.60g in horizontal tubular photobioreactors and bubble columns that have a continuous harvest. Finally, it was calculated that all of the project's photobioreactors (28,603.19ml in extension) produce 149.06 tons of biomass per day and 40,991.40 tons per year in 245 days of operation. (Table 1) [5]

Table 1. Biomass production calculations.

| Name                     | Tipe                   | Linear Meters (ml) | Total Volume (L) | Biomass productivity Per liter (gl-1 d-1) | Total productivity Per day (Ton) | Total productivity Per year (245day) (Ton) |
|--------------------------|------------------------|--------------------|------------------|------------------------------------------|---------------------------------|------------------------------------------|
| Curved Vertical Reactors | 1                      | 4.849,60           | 1.522.772,83     | 0.15                                     | 22.84                           | 6.281,44                                 |
| Inclined Vertical Reactors | 2                      | 4.496,32           | 1.285.948,66     | 0.15                                     | 19.29                           | 5.304,54                                 |
| Vertical Pyramid Reactors | 3                      | 5.987,47           | 2.418.939,09     | 0.15                                     | 36.28                           | 9.978,12                                 |
6. \textbf{CO}_2 \textit{fixation rate}

The photosynthetic fixation rate of \textit{CO}_2 starts from the stoichiometry of the fixation reaction of this gas for each gram of organic carbon. Each mole of \textit{CO}_2 contains 12 grams of C (44/12), so 3.66 g of \textit{CO}_2 is removed from the atmosphere for each gram of assimilated Carbon. For this reason, this data is inherent to each strain. In the case of \text{S}enedesmus Vacuolatus. It is 0.24g per liter per day in a semi-continuous culture and 1.15g per liter per day in a continuous culture [5]. Based on these data, the calculation of the \textit{CO}_2 fixation of the entire crop, were 250.17 tons per day and 68,796.41 tons per year in 245 days of operation. (Table 2)

| Name                                      | \textit{CO}_2 fixation rate (gl-1 d-1) | \textit{CO}_2 fixation rate per day (gl-1 d-1) | \textit{CO}_2 fixation rate per year (275 days) | \textit{CO}_2 fixation rate in Tons |
|-------------------------------------------|----------------------------------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------|
| Curved Vertical Reactors                  | 0.24                                   | 365.465,48                                    | 100.503.006,78                                | 10.050,30                         |
| Inclined Vertical Reactors                | 0.24                                   | 308.627,68                                    | 84.872.611,82                                 | 8.487,26                          |
| Vertical Pyramid Reactors                 | 0.24                                   | 580.545,38                                    | 159.649.980,07                                | 15.965,00                         |
| Vertical Pyramid Reactors For Slope       | 0.24                                   | 199.358,27                                    | 54.823.524,82                                 | 5.482,35                          |
| Flat Inclined Reactors                    | 0.24                                   | 341.145,04                                    | 93.814.886,88                                 | 9.381,49                          |
| Tubular Inclined Reactors                 | 1.15                                   | 177.280,52                                    | 48.752.142,08                                 | 4.875,21                          |
| Inclined Reactors with Bubbling Columns   | 1.15                                   | 529.265,42                                    | 145.547.989,74                                | 14.554,80                         |
| Total                                     |                                       | 2.501.687,79                                  | 687.964.142,20                                | 68.796,41                         |

7. \textbf{Methane Production}

The present work, only the amount of Biogas that can be produced from the volume of Biomass calculated previously will be calculated. To obtain the necessary data for the calculation of Methane production based on biomass, the results of the experiments proposed in the TFM "Biogas production from Microalgae and Cyanobacteria: Effect of thermal and alkaline pretreatments" of Alejandro González Calzada. [6]
This document analyzes the methane production values obtained between substrates pretreated with Lime and Sosa and untreated substrates. It was determined that the methane production within a biodigester can be up to 258 mL CH₄ / g SV corresponding to the pretreatment with 10% Sosa. (Table 3) With this database, it was possible to calculate the methane production per year:

| Name                                      | Type          | Linear Meters (ml) | Total Volume (L) | Methane productivity (L CH₄ / g SV)² |
|-------------------------------------------|---------------|-------------------|------------------|-------------------------------------|
| Curved Vertical Reactors                  | 1             | 4.849.60          | 1.522.772,83     | 58.931,31                           |
| Inclined Vertical Reactors                | 2             | 4.496,32          | 1.285.948,66     | 49.766,21                           |
| Vertical Pyramid Reactors                 | 3             | 5.987,47          | 2.418.939,09     | 93.612,94                           |
| Vertical Pyramid Reactors for Slope       | 3A            | 3.283,24          | 830.659,47       | 32.146,52                           |
| Flat Inclined Reactors                    | 4             | 6.580,73          | 1.421.437,68     | 55.009,64                           |
| Tubular Inclined Reactors                 | 4A            | 2.234,16          | 154.156,79       | 23.863,50                           |
| Inclined Reactors with Bubbling Columns   | 4B            | 1.171,67          | 460.230,80       | 71.243,73                           |
| Total                                     |               | 28.603,19         | 8.094.145,50     | 384.573,85                          |

The Labyrinth Park can produce up to 135.81 tonnes of methane per year. This means that it can power approximately 166 houses, since each ton of methane can power 3.5 houses with electricity.

8. Conclusions
A new type of urban landscape, through a park or technological garden that produces microalgae with a combination of vegetation, would allow not only to incorporate a new place of enjoyment in the city but also an energy factory that in 17.85 Ha (no. of hectares) would produce 40,991 tons of biomass to produce up to 384,573.85 L of methane (biogas) in one year. This biogas could feed the energy of 166 homes. The microalgal labyrinth, on the other hand, would absorb 68,796 tons of CO₂, which in a comparison of emissions would be equivalent to eliminating the CO₂ produced by 965,930 kwh, or the equivalent of the gasoline consumption of a car that traveled 361,618 km. In this way, the reinterpretation of the historical Labyrinth brings disruptive values to the city both from a new aesthetic and bio-technological understanding, giving the inhabitants of large cities an opportunity to enjoy the free air of pollution without the need for a pandemic to stop their rhythm and quality of life.

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