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TECHNIQUES FOR CAPTURING CO_2 IN PUBLIC HOUSING TOWARDS A SUSTAINABLE ARCHITECTURE*

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Abstract

Resting on the principle of self-regeneration, industrial symbiosis consists of a process in which the exchanges of raw materials, production waste, energy, water, services and competences are projected in order to realize a so-called "closed loop". Following a sustainable philosophy, particularly in recent years, the construction of "Green Buildings" – that are structures built through ecologically responsible processes and that can maintain efficient properties for their entire lifecycle – has spread. A green approach, moreover, can be also applied to the public housing sector, in which the construction of plants must be cost-effective for several actors and must reach an acceptable compromise between useful result and cost saving. The aim of the study, indeed, is to introduce techniques of "Carbon Sequestration", using Chlorophyta plants in hydroponic structure, in the public housing sector, operating costs analysis and environmental impact assessments to demonstrate "savings" resulting from the exploitation of techniques for capturing CO_2.

Keywords: industrial symbiosis, green building, techniques for capturing CO_2, technological innovations, recycling

1. Introduction

Every year, EU companies generate millions of tons of waste and about half of that is disposed in landfill. These impressive numbers are no longer sustainable, both from the environmental and the economic points of view, and they are due to the so-called "linear

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economy", which is opposite to the environmental-friendly concept of the "circular economy" (Cutaia et al., 2019).

Considering the importance, nowadays, of the promotion of a green and sustainable approach to business, the topic of the industrial symbiosis is introduced. The first definition of industrial symbiosis dates back to 1947, when Renner described it as "the complex of resource exchanges between two or more different industries" (Astarita, 2017). Moreover, this concept is sometimes linked back to what is called "industrial ecology", which is considered the science of sustainability (Allenby, 1999). A modern definition of industrial symbiosis depicts it as a form of intermediation to facilitate innovative collaboration between companies, so that the waste produced by one of them is valued as raw materials for another (Desrochers, 2010). So, the aim of both industrial ecology and symbiosis is to realize a circular model by involving traditionally separate industries in a process of business interaction, aimed at obtaining competitive advantages arising from the transfer of resources (by-products or production waste) between two or more dissimilar industries. At the end, it can be stated that industrial symbiosis is, therefore, a strategy for closing resource cycles and, thence, transforming a linear model into a circular one. In this way, industrial symbiosis allows, in addition, a group of companies to jointly maximize profit through the internalization of their externalities, in order to create important benefits to the business system and the community, both in economic and environmental terms (Domenecha and Davies, 2011). A significant example of an ecosystem symbiosis-based industry is the one in the Danish city of Kalundborg (Ehrenfeld, 2004).

Together with the circular economy, "Ecodesign" is also a cornerstone of the sustainable economic model. The principles of eco-design apply to all stages of the product's life cycle, with the aim of reducing its overall environmental impact: from the supply and use of raw materials, which must be reusable, biodegradable, recyclable and non-toxic at the time of working them in the production process and distribution. Ecodesign works thanks to the exploitation of a tool called LCA - Life cycle assessment methodology (ISO 14040), that allows the entire life cycle of a product to be assessed and so to analyze how it "interacts" with the environment (Frosch and Gallopoulus, 1989).

The circular economy is now a sector worth 88 billion turnover and 22 billion in value added, equivalent to 1.5% of national GDP, a sector that is therefore as attractive as other important sectors of economy, such as textiles or agriculture, and which boasts numbers that equate to the entire national energy sector (www.enea.it).

In conclusion, it can be assumed that industrial symbiosis, if applied at European Community level, can play a key role in the achievement of a shared circular economy, ensuring environmental protection in accordance with attempts to mitigate the consequences of climate change. In order to implement an industrial symbiosis route, a public research body has developed *ad hoc* instruments which are: a methodology for business involvement, symbiosis platform, the corresponding industrial resources, the Italian network of industrial symbiosis SUN for sharing and promoting experiences and various projects at EU level developing regional, national and international circular economy models through the approach of industrial symbiosis (Pecorino et al., 2018). In Italy, industrial symbiosis begins to be mentioned and indicated in different regional and local planning and addresses (Toni, 2015). The various examples which can be mentioned include the case of the Emilia-Romagna Region, which indicates industrial symbiosis in the Regional Waste Plan (2014) as a strategy to be adopted for the reuse and recovery of by-products, subject to the legislation (Arfò et al., 2019). The Lazio energy plan of 2016 included industrial symbiosis models among the instruments for changing the economic development model that decouples resource consumption from GDP (Mark et al., 2015). In addition, the Apea guidelines of the Lazio Region require the achievement of industrial symbiosis objectives for ecologically equipped production areas as a requirement (Bonanno et al., 2018; Giunta et al., 2018). The Cartesio network also mentions the fact that the project is a major factor in the development of the environment's industrial symbolism for ecologically equipped productive areas (La Cagnina et al., 2019). The Region Friuli Venezia Giulia provides, inter alia, for the promotion of industrial symbiosis in the regional waste prevention plan (2016). In 2016, the G7's work on industrial symbiosis found a continuation at the Tojama summit in Japan, where the Environment Ministers declared a common vision to improve resource efficiency and promote 3R (reduction, reuse and recycling) with ambitious actions by G7 members. One of these actions involves facilitating the development of new enterprises, job creation, and local revitalization through the setting up and use of local resources, assets, and energy based on cooperation between different local actors (industrial and social symbiosis) (Matarazzo, 2018).

The objective of this paper is to present the Carbon Sequestration techniques through Chlorophytum & comosum plants in hydroponic structures and to raise society awareness about the importance of the use of forest trees and ecosystems in terms of climate adjustment and biosphere mitigation. All green plants have the ability to transform the combination of carbon dioxide (CO_2) and water into carbohydrates and then release oxygen (O_2) into the environment. Plants need light to perform this transformation, also known as chlorophyllian photosynthesis. It is the basis of life on Earth (Lal, 2007).

The argument shows that a square meter of wall greening of "Chlorophytum comosum" can reduce carbon dioxide by approximately 1.15 kg per year and produce approximately 0.85 kg oxygen per year. This plant is not the most performing, but it was selected for the study because as much as it is very common and cheap. It is used as: apartment plant, for bordure, for pot crop on the balcony and also for the Greening system (Lal, 2005). The energy and material budget represent entry and exit on the basis of quantities of matter and energy (Matarazzo, 2016). According to the principle of balance, it must be achieved because matter and energy are converted only into a closed system and cannot be destroyed or created. In the case in question, energy can be exchanged for irradiation and heat conduction with a different system (an open energy system). The energy that flows into a system minus the energy that releases is equal to the change in the energy of the system (Matarazzo and Baglio, 2018). The data for the balance sheet - material was determined for an area of 25 diameter plants of 17 converted into a surface element of 1 square meter. The main influences in input are CO_2 (carbon dioxide), fertilizer and water; whereas outgoing is O_2 (oxygen), water steam, return water and growth, i.e. organic mass. The high efficiency of water use from the budget, gives information on the absorption of CO_2 through plant stems. The "Chlorophytum comosum" has the characteristic that transpires large quantities of water per unit of dry matter. One square meter of the surface requires 506 kg of water per year. The calculations have also shown that over 99% of the water absorbed can be downloaded from the evaporation for the atmosphere and then cooling air masses.

2. Case study: Morandi bridge

The case analyzed in the study concerns the application of a vertical garden in the pylons of the Morandi bridge, shown in Fig. 1, situated in Genova, Italy. Also known as the Ponte delle Condotte or Polcevera viaduct, the Morandi motorway bridge saw its original construction between 1963 and 1967 following the design lines of the engineer Riccardo Morandi.

Fig. 1. Morandi Bridge

Distinguished by the enormous amount of traffic that crossed the bridge every day, it represented one of the most important Italian road routes. The bridge also allowed, through the European road E80, to connect the northern regions of Italy with southern France.

On the 14^{th} of August 2018 at 11:36 am a tragedy occurred that still two years later continues to resonate in the hearts of the Italians who on that day witnessed, live or from television, the partial collapse of the Morandi bridge. The section of the bridge that overlooks the river and industrial area of Sampierdarena, 250 meters long, suddenly collapsed together with the support pylon number 9, causing 43 victims among the people on board the vehicles passing on the bridge and among the workers at work in the underlying AMIU ecological island declaring a state of emergency for the municipality of Genoa.

On the 9^{th} of February 2019, demolition operations began which led to the demolition of the more traditional portions of the deck of the western part of the viaduct during the year.

Following these events, the reconstruction work on the bridge began; the bridge was carried out in one year and eight months after the slaughter of 14 August 2018 and opened in August 2020.

The structure is available on 18 pylons which have an elliptical section of 3.0 x 9.5 m and they are placed with a height of 50 m. The perimeter of the pylon had to be found first: 22.12 m and then it has to be multiplied for the height in order to find the lateral area that is 1,106.5 m^2 for a single pylon. The sum of the 18 different side areas is 19,917 m^2.

The public building sector is investigated, with careful cost analysis and environmental impact decrease resulting from the application of CO_2 capture techniques, also including a project to implement the vertical garden of “Chlorophytum comosum” on the 18 pylons of the new Morandi bridge. The analysis of the case of the bridge reconstruction and the resulting hypothesis of inserting a vertical garden on the pillars, is extremely important for the study and evaluation of the application of carbon sequestration techniques especially in reference to the use of the plant “Chlorophytum comosum” (Rowe, 2010).

3. Materials and methods

Among CO_2 capture techniques, photosynthesis is one of the best processes, consisting of autotrophic organisms to produce glucose from water and carbon dioxide using sunlight absorbed by a particular photosensitive pigment, chlorophyll. The most important tool for the purpose of the study is certainly the carbon sequestration, substantial removal, capture or sequestration of carbon dioxide from the atmosphere to slow or reverse atmospheric CO_2 pollution and to mitigate or reverse global warming. All green plants have the ability to transform the combination of carbon dioxide (CO_2) and water into carbohydrates and then release oxygen (O_2) into the environment. Plants need light to perform this operation, also known as chlorophyllian photosynthesis (Shen et al., 2020).

The overall reaction of photosynthesis is schematized in the formation of 1 glucose molecules (with energy-rich links) and 6 oxygen molecules from 6 carbon dioxide molecules and 6 water molecules. The mechanism by which photosynthesis is performed may be split into two separate stages (light and dark phase), each consisting of a complex series of enzyme catalyzed reactions. These stages are linked to each other and are taken at two different places of chloroplast. In the light phase, the light absorbed by chlorophyll is used as a source of energy to break water molecules and to synthesize ATP (ADP) and NADPH (NADP+). Chlorophyll, certain ancillary pigments and electron transporter molecules are placed on the thylakoid membranes to form two groupings, photosystem I and photosystem II (Fig. 2). The "captured" light energy from the pigments of photosystem II is transferred to a particular chlorophyll molecule, which is the reagent center.

Reactive chlorophyll-center is "excited" and loses an electron from its electron that enters the electron transport chain. The flow of electrons along the chain provides the energy required for ADP synthesis of ATP (Sour, 2020). The argument shows that a square meter of wall greening of "Chlorophytum comosum" can reduce carbon dioxide by approximately 1.15 kg per year and produce approximately 0.85 kg oxygen per year; this numbers that have been calculated on the basis of an experiment performed with a similar plant but with a different perceptibility index (Getter et al., 2009).

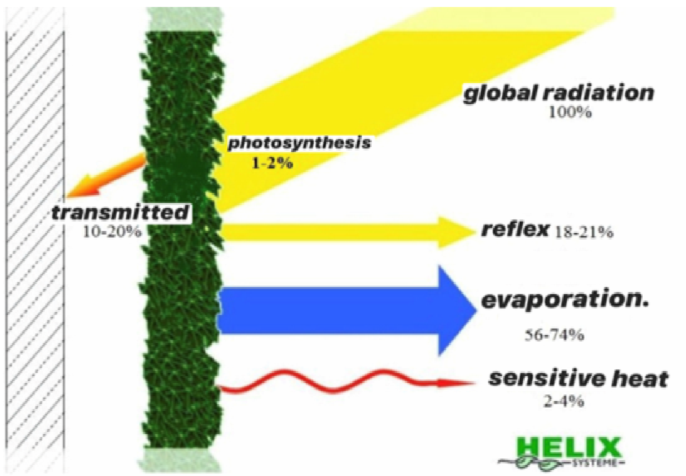

Fig. 2. Schematic illustration of the energy budget of a facade exposed to the south green oxygenase

4. Results and discussion

The Carbon sequestration is a technology that seems to be able to limit the effects of global warming by greenhouse gases. However, we must not forget that this is a transitional technology and as such it must have a limited time horizon. On a planet populated by seven billion people it would be a mistake to think otherwise. Having said that, science can help CCS not least. There are many good engineering perspectives, and scientific history showing that what was considered unthinkable is now possible. The development of this practice is not utopian an environmental and economic analysis of the implementation of a vertical garden of Chlorophytum comosum on the new Morandi bridge can be carried out.

In presiding the ceremony of the launch of the last campaign of the new Polcevera Viadotto Genoa, he was the President of the Council of Ministers of the Italian Republic, Giuseppe Conte.

Looking at the geometry of the new St. George Bridge, it has a surface vertical garden useful exposure of at least 250 square meters on average active for each a total absorbent area of more than 4,000 square meters (value minimum prudential expected that the 18 supports are not all exposed with the same surface - active solar).

It is important to analyze also economically the implementation of a green walling to verify if it is actually convenient from the financial point of view.

One square meter of “Chlorophytum comosum” consisted of approximately 25 vase plants with 18 cm diameter, a single plant usually costs on average of € 3 in nurseries and retail shops; by going to carry out a large-scale plan, the plants will be purchased at a price lowered by 30% and then approximately € 2.10. For fixing plants, self-perforating screws, mechanical and steel washers are required to ensure the duration and safety of the work overtime against the corrosion of water and failure. The self-performing screw is usually sold at 25 set at a price of € 9.2 per wholesale price and thus € 6.44 mechanical rates a retail price of € 9.80 (wholesale € 6.9) and steel washers at 25 set at a retail price of € 7.29 (wholesale € 5.1). One square meter of wall greening requires 506 kg of water per year, which is sold at € 1.37 per cubic meter, which corresponds to approximately 1,000 kg of water, so there is a water cost of 0.7 per square meter. To implement “a carpet” one square meter of wall greening “Chlorophytum comosum” costs € 71.65, broken down in 52.5 of plants, 18.45 of fasteners and € 0.7 of water consumption. This budget does not include labor and transport costs as varying from the type of project.

Since the cost of implementing a unit of green walling of “Chlorophytum comosum” is € 71.65, therefore the total cost of the project is € 286,000 without taking into account labor costs.

The total cost of the project was found by calculating the side area of the bridge pylon which through the calculations shown in is 250 m^2, multiplied by 18 (total number of pylons) and then by € 71.65, the price per m^2 of the green walling.

These are important numbers because, since the bridge is a place where polluting gas is produced, it is essential to find a solution that can limit these effects. In more application terms, considering the average transit of 5 to 6 cars and/or industrial vehicles per second for 13.85 hours/d (average time), the result of freeing up urban area from CO_2 emissions into the atmosphere, as the amounts of about 10 g/km of CO_2 (MCI passengers cars/industrial vehicles), are emitted on average by 1 km and would be produced in total a year almost 1.000 t : 5.5 x (10/1000) x 3,600 x 13.85 x 365 = 1,000,939.5 kg CO_2. Thanks to the solution proposed in this paper, the damage associated with the emission of urban traffic can be limited. It’s possible to make a comparison with implementing a green walling of “Hedera Helix”, first it’s necessary an economic analysis: The cost of a seedling of “Hedera Elix” is € 7.9 per jar and therefore € 5.5 wholesale; taking into account that in one m^2 must go there 25 seedlings of diameter 17 cm you will consider a cost of seedlings of € 137.25 (25 x € 5.5), to which the costs of the fixing material must be added: € 18.45 and € 0.7 of water; therefore, a m^2 of green walling of “Hedera Helix” will cost € 157.4.

By multiplying the price per m^2 by 250 m^2 (the lateral area of the pylon) and for 18 (the total number of pylons) you will get the cost of the entire project: € 629,600. From the environmental point of view, the resulting data of the experiment shown above is for the absorption of CO_2: 2.3 kg per year and 1.7 kg of O_2 release per meter framework.

Multiplying these indices by 250 m^2 (the lateral area of the pylon) and by 18 (the total number of pylons) you will get that 9,200 kg of CO_2 will be absorbed and 6,800 kg of O_2 released. With this type of plant we talk about more important numbers both from the environmental and economic points of view; in fact both the results of environmental performance and the overall cost are approaching twice the project of the "Chlorophytum comosum", therefore it will be necessary to make a choice in terms of cost and benefits between the two types of projects.

5. Concluding remarks

One of the actions to mitigate anthropogenic climate change, specifically to reduce carbon dioxide (CO_2) emissions from coal-fired power plants and other industrial sources, it is commonly believed to be the Carbon Capture and Storage (CCS). The idea was promoted by the Intergovernmental Panel on Climate Change. However, in a global perspective to have some significance in reducing the accumulation in the atmosphere of greenhouse gases CCS must operate at a massive scale, in the order of 3.5 Gt (billions of tonnes) of CO_2 per year, a volume about equivalent to the 30 billion barrels of oil produced annually in the world (you imagine that CO_2 could go to occupy the pores of the rock freed from oil). Large-scale application is still a hypothesis that cannot be implemented in the medium term, since there are many technological and economic problems to be solved. It is estimated that 20-30 years are needed for the fine-tuning process, more for that of storage.

From the paper it can be noted that in the public building sector it is possible to achieve various environmental and social advantages.

The choice as a fundamental principle of bioconstruction was to use completely natural products from wood to other components that allow perfect forbidding and at the same time do not harm human health. The use of completely natural materials has initially led to higher prices than traditional ones for which bio-construction building was considered an elite market. Contrary to what was thought, investment in bioconstruction, although it has a higher initial cost, makes it possible to recover this cost with lower consumption and very low maintenance of the buildings.

As the constructive market in bioconstruction, the materials used have fallen in cost so that today is the same cost as natural materials traditionally used and many advantages compared to before.

In fact, investigating the "Carbon Sequestration" studies how the presence of broad-leaved plants can contribute to the reduction of CO_2 in the air and the increase in O_2. Among the different plants that present these attributes, the plant "Chlorophytum comosum" was chosen as it is easily found and has a low price.

Being an analysis carried out per m^2, it is possible to have economic and environmental indicators that can be applied to any surface and that is easily introduced in the public building sector.

The State should intervene for the use of these technologies by reducing taxation or providing economic incentives; while businesses should start raising awareness because, if these technologies are in opportunity today, tomorrow will be an obligation.

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