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Analytical Trends of Building Morphology as a Passive Strategies to Promote Outdoor Air Quality

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ABSTRACT: Poor air quality can be considered one of the main effects of urbanization phenomenon nowadays. As outdoor air pollutants affect directly or indirectly on the air quality either indoor or outdoor spaces, which leads to many actual risks. Consequently, researches enquired how to invest the morphology of buildings to promote outdoor air quality. Several global trends have proposed building morphology approach as a passive strategy to promote outdoor air quality, because of its major impact in improving the dispersion of air pollutants in the built environment. Therefore, this research analyses the global trends and techniques of international case studies to present the power of the building morphology to promote outdoor air quality.

KEYWORDS: Outdoor air quality, Promoting strategies, Air pollutants dispersion, Building morphology

I. INTRODUCTION

Based on the reports of the World Health Organization (WHO), the outdoor air quality can be considered environmental health problem affecting directly or indirectly on the human health, environmental stability all over the world [1-3]. Consequently, several researchers proposed strategies regarding controlling pollutants emissions, as active strategies [10-14], as well several passive strategies indicated the effect of solid barriers[4], photocatalyst materials [5], vegetation[6-12], and urban morphology [13-15]. However, few studies analysed global trends of building morphology as a passive strategy to promote outdoor air quality.

Regarding outer skin, surface deposition, and photocatalyst materials can present the main techniques to reduce air pollutants. Mechanical, and vegetation deposition create an efficient pollutant filter especially NO_2 , and PM_{10} generally. However vegetation deposition surfaces like green walls can promote air quality, regulates the traffic noise level of busy streets, besides presents a way to abate the effects of climate change and global warming [16, 17]. On the other hand, during the past two decades, Advanced Oxidation Processes (AOPs) have been used as an alternative strategy to reduce hazardous organic materials [61]. One of the main methods of AOPs is the photocatalytic reactions, which can be considered a natural reaction occurring in the presence of light, water, and oxygen. For instance, titanium dioxide has wide applications in various finishing materials to reduce air pollutants [18].

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Consequently, this research investigates the influence of the recent trends related to the building morphology, and vegetation or photocatalyst materials to promote outdoor air quality through the analysis of seven international examples; including high- and low-rise building. Accordingly, the paper is organized as follows. Section II describes the building morphology approach; including high, and low-rise buildings. After the discussion of building morphology approach, seven examples will be analysed in Section III. Section IV discusses the results of analytical trends will be discussed. Finally, Section V presents the conclusion.

II. BUILDING MORPHOLOGY

The morphology of buildings can be present as a passive strategy to dilute air pollutants' concentrations, hence promote outdoor air quality [19-21], as the buildings can be considered roughness elements, which modifies the velocity field close to the façades, hence mechanical turbulence [22, 23]. In relatively, Latifi et al. [20] have confirmed that the roughness elements of buildings can:

- Reduce the local forces on the building façade
- Damp the strong pressure fluctuations on buildings walls and roofs
- Modify the velocity field, by making a more uniform pattern on the facade or canalizing the airflow and moving it in different zones

Consequently, the following analytical approach will focus on the influence of building morphology through both high, and low-rise buildings.

1) High-rise building

The morphology of high-rise buildings provides the dispersion of air pollutants, hence promote outdoor air quality as well [24]. Whereas, the high-rise buildings enable the following techniques:

- Promote vortices to become incoherent and shed at different frequencies at different heights
- Reduce vortex-induced vibrations along the building height
- Enable the vortices to shed over a broad range of frequencies

2) Low-Rise Building

The building morphology of low-rise buildings depends mainly on the following vortex techniques:

- Enhance straight sharp edges, which create the vortices
- Develop the vortex formation
- Deflect the vortices

These previous techniques can change the flow patterns around low-rise buildings, hence promote outdoor air quality [25, 26].

III. ANALYTICAL TRENDS

Based on introducing the main techniques of building morphology in promoting outdoor air quality, the following selection of projects depends on integration between more than promoting technique to provide the power of the building morphology, as a passive strategy to promote outdoor air quality.

Analysis of the projects will include project definition, main concept, besides promoting strategies as well. The first five projects present trends of high-rise buildings, however, the rest projects present trends of low-rise buildings. In addition, the analysed projects can be ordered owing to their main promoting strategies (see Fig. 1); as the first project depends on photocatalytic reactions (Table 1), while the second, and third projects based on vegetation deposition as shown in Table 2& Table 3. In addition, Table 4 and Table 5 illustrate projects, providing mechanical deposition. On the other hand, low-rise buildings present only photocatalytic reactions, with various patterns (see Table 6& and Table 7).

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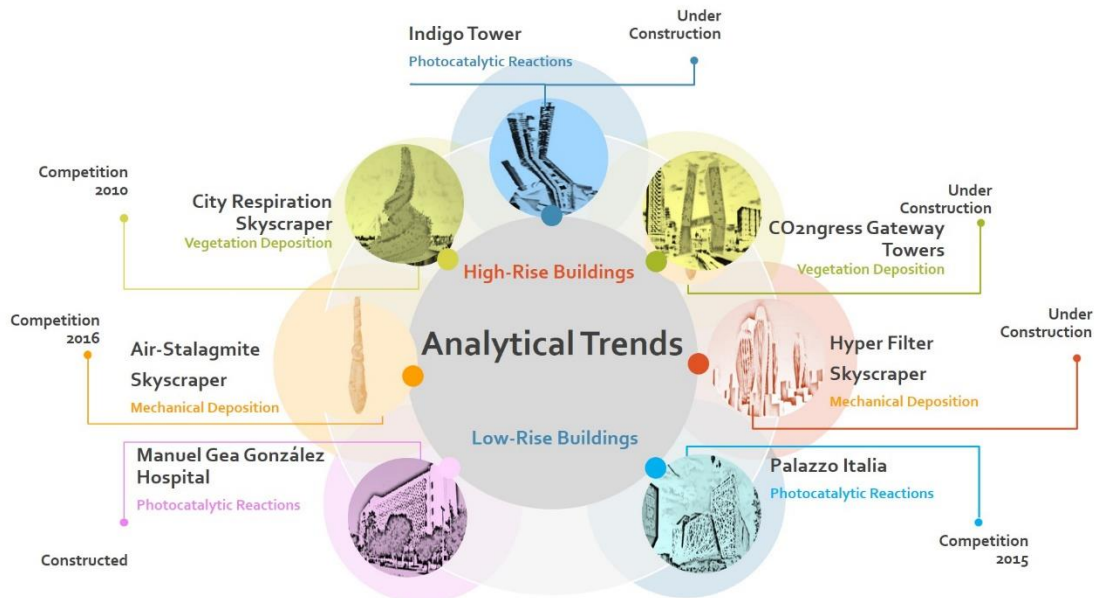
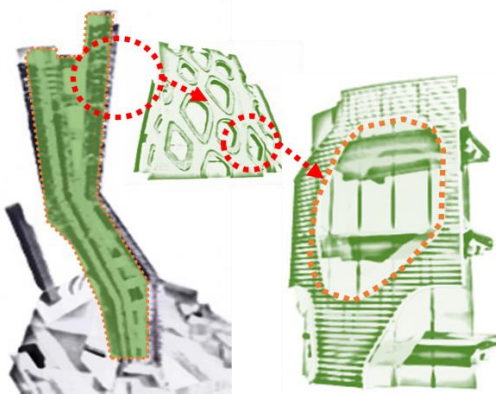


Fig. 1 Analytical trends of high, and low-rise buildings.

Table 1: Analysis of Indigo Tower. Source the authors based on [34-36].

Indigo Tower		
Project definition	Location	Qingdao, China
	Year	2010
	Designer	Ted Givens, Benny Chow, and Mohamed Ghamlouch
	Goal	The building aims to purify the air of cities through the benefits of a TiO ₂ skin.
Main concept	The main concept of Indigo Tower basically depends on the morphology of this tower generally, besides skins' shapes and apertures in particular to promote the building's envelope in order to enhance the amount of air being purified.	
Promoting strategies	<p>The Indigo Tower depends on following techniques to promote outdoor air quality as the followings:</p> <ul style="list-style-type: none"> Focus and increase wind speed, which not only power a series of vertical wind turbines, but also pushes the air across the TiO₂ The skin design is inspired by the pocketed and cellular texture of the TiO₂ molecule. Such skin floats off the building to conceal the UV lights, and further maximizes the building's envelope, photocatalyst purifying; enhancing the amount of air being cleaned 	

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Table 2: Analysis of City Respiration Skyscraper. Source the authors based on [31, 32].


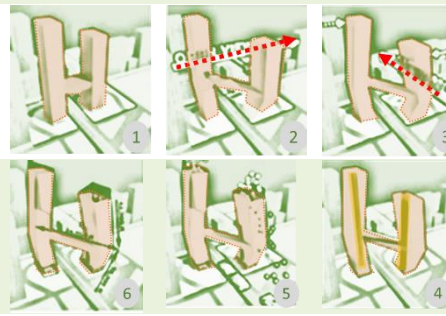
City Respiration Skyscraper		
Project definition	Location	Shanghai, China
	Year	eVolo competition 2010
	Designer	Pavína Doležalová and Jan Sméka
	Goal	The designers have proposed that a network of these skyscrapers; placed in the most polluted areas; could strategically clean a city in a couple of weeks.
Main concept	<p>The main concept of city respiration skyscraper has been formed as a 3D cluster of individual concrete three spike units, which inspired by sea sponge to bring purified and oxygenated air back into the world's metropolises as a medium of purification.</p> 	
Promoting strategies	<p>This 240m swirling skyscraper depends on two techniques to improve outdoor air quality as the followings:</p> <ul style="list-style-type: none"> The structure of this skyscraper is designed to cleanse city air via it's helicoidally structure, which acts as a chimney to capture polluted air at the bottom and filtered by the algae. Algae and specialized water-sprayed system, which covered building skin act as sea sponge. 	

Table 3: Analysis of CO2ngress Gateway Towers. Source the authors based on [29, 30].

CO2ngress Gateway Towers		
Project definition	Location	Eisenhower Expressway, Chicago, USA
	Year	2012
	Designer	Danny Mui and Benjamin Sahagun
	Goal	CO2ngress Gateway Towers aim to present an innovative architectural example to merge carbon capture technology with urban planning and design.
Main concept	<p>Owing to the busy location of this project, which sees as many as 77,000 cars a day, the primary concept involves two crooked buildings that are outfitted with a filtration system in order to feed captured CO₂ to algae grown in the building's interior, which then converts it into biofuels.</p> <p>The main concept of CO2ngress Gateway Towers follows the following sequence:</p> <ul style="list-style-type: none"> Two towers on two sites Pull apart to open up view for adjacent building Pinch top to create "Gateway Experience" for vehicles Vertical Circulation Algae bioreactor tubes are placed near the communal terrace Tower structurally connected by a bridge 	
Promoting strategies	<p>The CO2ngress Gateway depends on the following techniques to promote outdoor air quality as the followings:</p> <ul style="list-style-type: none"> Irregular shape of the towers has been optimized to channel air pollutants through CO₂ scrubbers The double skin façade is enclosed by bio-reactor tubes, which grow the algae responsible for biofuel processing, besides reducing traffic noise 	

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Table 4: Analysis of Air-Stalagmite skyscraper. Source the authors based on [27, 28].

Air-Stalagmite skyscraper		
Project definition	Location	Begin, China
	Year	eVolo competition 2016
	Designer	Changsoo Park and Sizhe Chen
	Goal	This skyscraper is designed to filter polluted air and capture suspended air particles.
Main concept	Air pollutants can be introduced into the tower through the vacuum fan to discharge filtered clean air to the outside. In this context, particulates of air pollutants are accumulated and reused as composited building material with concrete through 3D printing method.	
Promoting strategies	<p>The Air Stalagmite can be considered as a massive structure to promote outdoor air quality through three techniques as the followings:</p> <ul style="list-style-type: none"> The morphology of skyscraper has channelled air pollutants to internal vacuum. A massive vacuum placed at the bottom of the building sucks polluted air to be cleaned by a series of air filters located on the higher levels. 3D printers can be used to create an organic mega-sculpture out of it, which gets thicker and more detailed, to further construct the skyscraper. 	

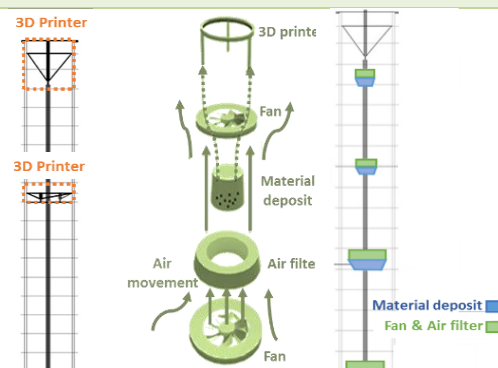
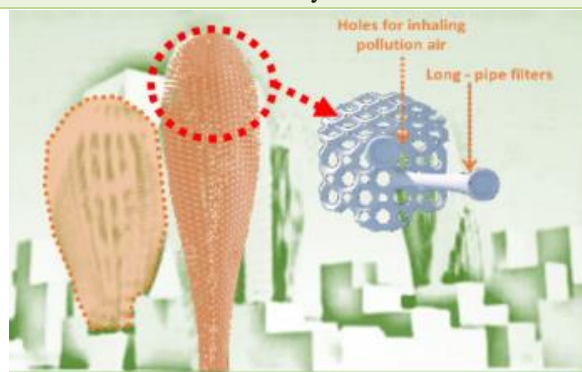


Table 5: Analysis of Hyper Filter Skyscraper. Source the authors based on [29, 33].

Hyper Filter Skyscraper		
Project definition	Location	Russia
	Year	2014
	Designer	Umarov Alexey
	Goal	The Hyper Filter project seeks to merge pollutants capture technology with the building's design to solve the regional air pollution problem in big cities between skyscrapers, depending on the principle of photosynthesis.
Main concept	This Skyscraper is designed to inhale air pollutants and exhale concentrated oxygen. The skin of the project is made out of long pipe filters that ensure the cleaning process. While clean air is released to the atmosphere, all the harmful substances are stored for use in the chemical industry for later use.	
Promoting strategies	<p>The Hyper Filter Skyscraper envelope structure is designed to provide the followings:</p> <ul style="list-style-type: none"> Proportional clear air emission to the over-building space. Temperature balance of the building. The biomimetic design uses long pipe filters in the air purification process and stores harmful substances on uptake to holders. 	



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Table 6: Analysis of Manuel Gea González Hospital. Source the authors based on [3, 21, 29, 37, 38].

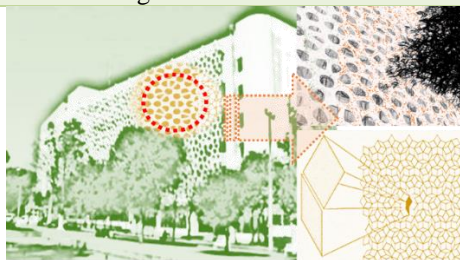
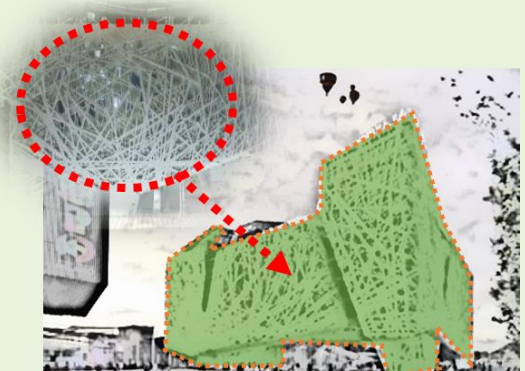
Manuel Gea González Hospital		
Project definition	Location	Mexico City, Mixic
	Year	2013
	Designer	Allison Dring and Daniel Schwaag
	Goal	<p>Considering the fact that Mexico City is one of the most densely polluted cities in the world, this building features a “smog-eating” façade that covers 2,500 square meters and has contained titanium dioxide pigments, purifying the emissions of an impressive 1,000 vehicles per day.</p> 
Main concept	The main concept of this project depends on the façade's design of Berlin-based Elegant Embellishment's first full-scale installation, which could negate the effects of 1,000 vehicles each day.	
Promoting strategies	<p>The outer façade of Manuel Gea González Hospital depends on patterns' design to promote outdoor air quality as the followings:</p> <ul style="list-style-type: none"> The molecular design of facades' patterns; executed by prosolve370e and designed by Elegant Embellishments; represents a large surface across a compact space: Large surfaces = large amounts of smog absorption Photocatalyst coating could react with ambient ultraviolet light to neutralize air pollutants, like NO_x and VOCs, breaking them down to less harmless amounts of carbon dioxide, and calcium nitrate and water. 	

Table 7: Analysis of Palazzo Italia. Source the authors based on [21, 29, 39].

Palazzo Italia		
Project definition	Location	Milan, Italy
	Year	2015
	Designer	Nemesi & Partners firm
	Goal	Palazzo Italia draws on the concept of an ‘urban forest’, with 900 cladding panels to reduce air pollutants.
Main concept	The design of Palazzo Italia has won the competition of designing Italy Pavilion at Expo Milan 2015, owing to 13,000 m ² of smog-eater.	
Promoting strategies	<p>The outer façade of Palazzo Italia depends on two techniques to promote outdoor air quality as the followings:</p> <ul style="list-style-type: none"> The irregular facades' patterns provide air pollutants dispersion to be purified by photocatalyst cement. 13,000 m² tiles of “biodynamic” cement have installed to capture air pollutants across six floors, and turns them into inert salts in direct sunlight 	

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IV. RESULTS OF ANALYTICAL TRENDS

Based on the previous analytical section, it is obvious that the morphology of global trends of buildings depended on two following consequences; the first one presents the morphology of buildings that varies between tapering, twisting, and varying cross-section, in high-rise building, which leads to provides the vertical transport of outdoor air pollutants. The second sequence based on the integration either mechanical or vegetation deposition or photocatalyst materials to purify outdoor air pollutants based actually on passive techniques., as illustrated in **Error! Reference source not found.**

Table 8: Promoting techniques of analytical trends.

		Building Morphology				Integrated Strategy			Influence of Promoting Strategy
		Twisting	Tapering	Varying cross-section	Facade patterns	Vegetation deposition	Mechanical deposition	Photocatalytic Reactions	
High-Rise Buildings	Indigo Tower	x	x	√	√	x	x	√	<ul style="list-style-type: none"> Shed vortices to over a broad range of frequencies Develop the vortex formation Purify outdoor air pollutants
	City Respiration Skyscraper	x	x	√	√	√	x	x	<ul style="list-style-type: none"> Shed vortices to over a broad range of frequencies Deflect the vortices Purify outdoor air pollutants
	CO2ngress Gateway Towers	x	x	√	√	√	x	x	<ul style="list-style-type: none"> Shed vortices to over a broad range of frequencies Purify outdoor air pollutants
	Air-Stalagmite skyscraper	√	x	x	x	x	√	x	<ul style="list-style-type: none"> Reduce vortex-induced vibrations along the building height Develop the vortex formation Purify outdoor air pollutants
	Hyper Filter Skyscraper	x	√	x	√	x	√	x	<ul style="list-style-type: none"> Enhance vortices to become incoherent and shed at different frequencies at different heights Deflect the vortices Purify outdoor air pollutants
High-Rise Buildings	Manuel Gea González Hospital	x	x	x	√	x	x	√	<ul style="list-style-type: none"> Only photocatalytic materials can purify outdoor air pollutants
	Palazzo Italia	x	x	x	√	x	x	√	<ul style="list-style-type: none"> Deflect the vortices Enhance air pollutants dispersion, and purify outdoor air pollutants

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V. CONCLUSION

Owing to the serious health and environmental risks of outdoor air pollutants, passive strategies have been proposed to promote outdoor air quality. Accordingly, this study emphasizes on the influence of building morphology as a passive strategy for promoting the dispersion of outdoor air pollutants through microclimate factors.

This paper analysed global trends of various; including high, and low-rise buildings. Analytical trends of building morphology as a passive strategy present obviously great potential for recent techniques of promoting outdoor air quality, especially for high-rise buildings. As the morphology of high-rise buildings provides the vertical transport of outdoor air pollutants, which can be considered an essential phase for pollutant dispersion. Furthermore, adding new functions to finishing materials presents a significant passive technique to purify outdoor air pollutants efficiently.

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