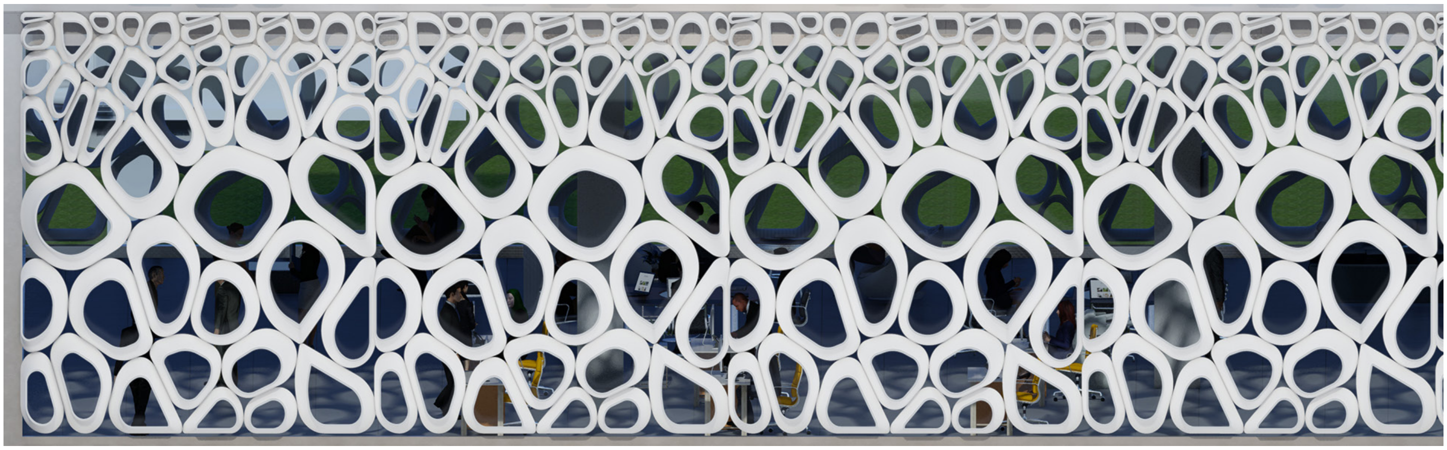
A PHOTOCATALYTIC FACADE FOR AIR POLLUTION MITIGATION



Dante Gil Rivas

TABLE OF CONTENTS

I. INTRODUCTION

Indoor air pollution ensued from various Volatile Organic Compounds (VOCs) in building materials and outdoor air pollution by the automobile exhaust gases pose serious threats to people's health and the environment. A data set collected from 100 randomly selected buildings in 37 cities in 25 states shows that all buildings contain carcinogenic VOCs, with the majority of the buildings containing more than a dozen different VOCs (EPA, 2020c). Take formaldehyde as an example, although the concentration measured from the buildings, ranging from 3 ppb (parts per billion) to 26 ppb, often exceeds the exposure limit of 16 ppb set by the National Institute for Occupational Safety and Health (Berkeley Lab, n.d, CDC, 2019). Exposure to VOCs can cause health risks, from mild irritations to severe cancers.

As a primary source of outdoor air pollution from fossil fuel combustion, nitrogen oxides (NOx) react with other chemical components in the air and form secondary pollutants, including particular matters, ground-level ozone, and various other toxic gases. The creation of ozone can go even further to form photochemical smog. Part of this exposure's reality is that certain people are impacted by the effects more than others, specifically POC (People of Color) from low socioeconomic status (low-SES). Because of this exposure, there is a disparity in the impact of air pollution and air quality amongst racial and ethnic groups, resulting in a difference in the quality of life (ALA, 2020a).

The proposed solution of this study is to aid in this environmental and inequality battle. The solution is an air depolluting facade that uses titanium dioxide (TiO2) to improve the air quality by removing VOCs and converting NOx in the air to harmless byproducts. Many studies show that UV-A rays with a wavelength shorter than 385nm (nanometer) can excite Titania (TiO2) (Madhusudan, 2003) to break down VOCs, such as formaldehyde (Yang, 2000) and dichloromethane (Alberici, 1997), into non-toxic gaseous matters often including carbon dioxide and water vapor, through photocatalytic oxidation processes. The facade aims to improve the interior air quality (IAQ) of occupants, resulting in improving the occupants' health and productivity.

II. BACKGROUND INFORMATION

A. VOLATILE ORGANIC COMPOUNDS (VOCs)

The origin of VOCs is divided into two different categories. The first category is natural VOCs, also known as biogenic VOCs. These are compounds produced by the growth, development, reproduction, and defense of plants. The VOCs in plants have a high chemical reactivity that functions as a form of communication between plants and insects. Because of this high chemical activity and the large emission rates from plants into the atmosphere, plants significantly affect the atmosphere's physical characteristics (Laothawornkitkul, 2009). The second category is located in urban areas from anthropogenic sources like traffic, natural gas leakage, fossil fuel combustion, and petroleum refining. The most dominant anthropogenic sources of VOCs in the air are from vehicular exhausts and industrial emissions. VOCs can be categorized even further, but as indoor organic pollutants organized by the World Health Organization (WHO) as very volatile organic compounds (VVOCs), volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs) (EPA, 2017b).

VOCs are carbon-based chemicals that can quickly evaporate at room temperature. The chemical and physical properties they possess have been primarily used in consumer products such as paints, pesticides, wood preservatives, air fresheners, automotive products, hobby supplies, office equipment such as printers, correction fluids (white-out), various adhesives, and markers (EPA, 2017a). The few examples stated have become the sources for VOCs in an indoor environment. According to the Environmental Protection Agency (EPA), the variety of chemicals in various products have increased VOC concentration ten times indoors than outdoors. Higher concentration of VOCs have short-term and long-term health effects that range from eye, nose, and throat iterations, headaches, loss of coordination, damage to the liver, kidney, and central nervous system, to even some being suspected or known to cause cancer in humans (EPA, 2017a).

B. AIR POLLUTION

VOCs do not only act on their own, but also react with other gases such as nitrogen oxides (NOx) (EPA, 2019c). The combination of the VOC in the atmosphere, the nitrogen oxides released from car exhausts, coal plants, factory emission, and the light from sunlight form tropospheric ozone/ground-level ozone, also known as "bad" ozone. As opposed to the "good" ozone in the stratosphere that protects us from the sun's harmful ultraviolet rays. Ground-level ozone is a harmful air pollutant because of the adverse effects on people and the environment (EPA, 2021a). Once ground-level ozone is formed, it becomes the ingredient to produce smog, specifically photochemical smog. There is another form of smog called sulfurous smog, but this smog is not what the proposed technology is aimed to solve as it has different properties. Photochemical smog is a mixture of various pollutants formed when NOx, VOCs, react to sunlight, combinations of other gases, and particle pollution (EPA, 2016b).

Ground-level ozone effects are felt the most during hot sunny days in the urban environment when it can reach unhealthy levels. Not only are urban environments affected, but so are rural environments as the ozone can be carried long distances by wind (EPA, 2021a). Because of the range, ground-level ozone has certain people more at risk than others. According to the EPA, the people who are at the most risk are, “people with asthma, children, older adults, and people who are active outdoors, especially outdoor workers. In addition, people with certain genetic characteristics, and people with reduced intake of certain nutrients, such as vitamins C and E, are at greater risk from ozone exposure. Children are at greatest risk from exposure to ozone because their lungs are still developing and they are more likely to be active outdoors when ozone levels are high, which increases their exposure. Children are also more likely than adults to have asthma” (EPA, 2021b). The health effects of ozone pollution can range from immediate breathing problems such as: shortness of breath, wheezing, coughing, asthma attacks, increased risk of respiratory infections, increased susceptibility to pulmonary inflammation, increases the needs for people with lung diseases like asthma or chronic obstructive pulmonary diseases (COPD) the need to receive medical treatment. Long term exposure to ozone, though specifics of time can only be found from one source, are people who are exposed for periods longer than eight hours a day. Some people may experience this exposure for days, months, years. The results of the extended exposure results in permanent lung damage and abnormal lung development in children (ALA, 2020b).

C. ENVIRONMENTAL IMPACT

There are various impacts NOx can have on the environment. When NOx interacts with water, oxygen, and other chemicals in the atmosphere, it can form acid rain (EPA, 2016a). Acid rain can affect the ecosystem, wildlife, and plants. For example, acid rain can remove nutrients and minerals from the soil that the plant needs to grow (EPA, 2020a). The next impact of NOx is that it can make the air hazy, reducing visibility (EPA, 2020b). When air pollution absorbs light, it can reduce the clarity of what we see. Lastly, another impact NOx has on the environment is eutrophication, also known as nutrient pollution. Nutrient pollution is defined by the National Ocean and Atmospheric Administration (NOAA) as, "the process where too many nutrients, mainly nitrogen and phosphorus, are added to bodies of water and can act like fertilizer, causing excessive growth of algae" (NOAA, 2009). According to the EPA, the increase in algae can "harm water quality, food resources and habitats, and decrease the oxygen that fish and other aquatic life need to survive. Large growths of algae are called algal blooms and they can severely reduce or eliminate oxygen in the water, leading to illnesses in fish and the death of large numbers of fish" (EPA, 2019b).

D. HEALTH IMPACT

Similar to the effects of ground-level ozone, breathing air with a high concentration of NO2 can irritate the human respiratory system. Exposure to short periods of NO2 according to the EPA, "can aggravate respiratory diseases, particularly asthma, leading to respiratory symptoms (such as coughing, wheezing or difficulty breathing), hospital admissions and visits to emergency rooms'' (EPA, 2016a). More prolonged exposure to NO2 can result in the development of asthma and increase respiratory infections. The people most at risk are children and elderly people.

Exposure to air pollution is linked to neurodevelopmental disorders in children. Various human studies were conducted on human exposure to combustion-related air pollution, with one of the culprits being NO2. According to a group of researchers, these effects are: "adverse effects on brain development, including deficits in intelligence, memory, and behavior. Other studies have linked roadway proximity to decreased cognitive function, including deficits in memory and attention" (Payne-Sturges, 2019). Relating to neurodevelopmental disorders is PM 2.5, which is defined as tiny particles or droplets that are two and one-half microns less in width (EPA, 2020d). Their size causes them to travel deep in the respiratory tract reaching the lungs. PM 2.5 is formed in three ways according to the EPA. "1) it is directly emitted from the tailpipes of cars, trucks and other on-road vehicles, 2) it is re-entrained from materials found on the roadway (typically known as fugitive dust), and 3) it is created by secondary formation from precursor emissions such as sulfur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs) and ammonia (NH3) (Hodan, n.d). Because NOx and VOCs are related, the effects on the brain have been associated with "developmental delay; reduced IQ; symptoms of anxiety, depression, and inattention; ADHD; and reduced size of brain regions important for processing information and impulse control" (Payne-Sturges, 2019).

E. EQUITY IMPACT

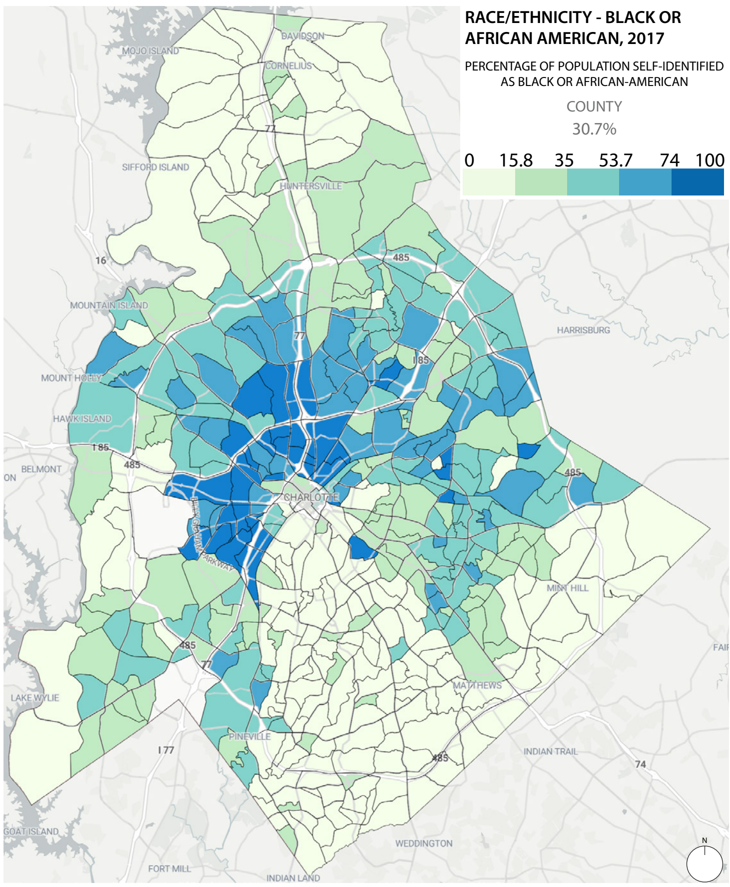
People who live near polluted areas have less access to basic needs. A report from the American Lung Association focuses on issues and research related to anything that impacts the lungs. In an article they published, they mentioned how air pollution relates to disparities among POCs. POCs have less access to health care, grocery stores, and good jobs. Instead, POCs have poorer job opportunities, dirtier workplaces, and higher traffic exposure that could handicap various groups of people (ALA, 2020a).

"Pollution, much like wealth, is not distributed equally in the United States" (Lambert, 2019). According to several studies, air pollution exposure was more prominent in POCs than whites. Studies show that air pollution is disproportionately caused by white American's consuming goods and services, yet disproportionately inhaled by black and American Hispanics. Researchers at the University of Washington did a series of studies between 2000 and 2010. Their findings found disparities between in NO2 exposure based on race and ethnicity, rather than income, age, or education. In the span of the research, there was a decrease in NO2 for non-white populations of 17.6 ppb to 10.7 ppb and 12.6 to 7.8 for the white population. The reduction of NO2 went from 40% to 37% for nonwhites. In 2000, the concentration of NO2 with the highest nonwhites population was 2.5 times higher than in neighborhoods with the lowest proportion of nonwhite residents. The value in 2010 increased from 2.5 to 2.7. The study concluded that if POCs breathed lower NO2 than the white population in 2010, it could have prevented an estimated 5,000 premature deaths from heart disease (Clark, 2017).

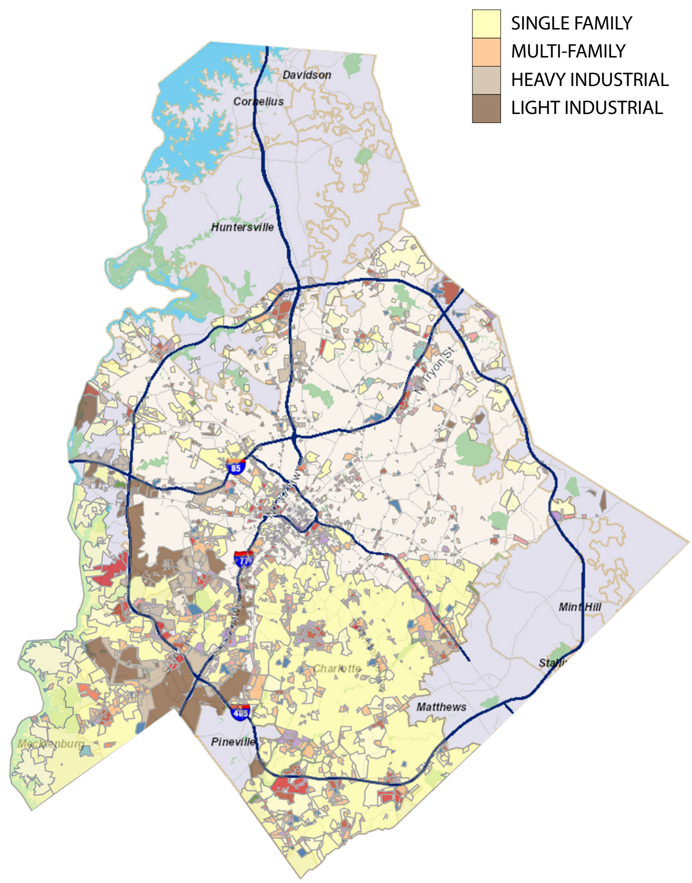
A study conducted from 1988-2009 in California looked at 352,053 patients newly diagnosed with lung cancer ascertained by the California Cancer Registry. There was an estimate of the exposure the people had with the ambient air pollution conducted after each follow-up period for each resident. The result was that the exposure to the ambient air shortened their survival, with NO2 being one of the various culprits (Eckel, 2016).

Redlining has contributed to the impact of asthma on children of color. According to a study, the segregation of POC experienced during the last century contributes, if not cause, the disproportionate burden of ambient air pollution (AAP) experienced by POCs today. Redlining in the 1930s forced POCs into less-desirable neighborhoods. POCs experience disparities in access to resources, psychological stressors, and AAP exposure are linked to the historical practices of structural discrimination in the United States. Not only are the health of children of color affected, but so are the family's finances. The cost of asthma in the United States is estimated to be $81.9 billion. According to the study, this cost is felt the most by SES communities of color, who experience twice as many unplanned health care visits, which adds to the excess in medical costs and visits to the physician. Relating to the increase in doctor visits, children of color experience twice as many missed school days which correlates to poor academic performance. A recent study in the United States shows that asthma is most prevalent in African American children at 15.7% and 12.9% in Puerto Rican children. Compare this to non-Hispanic white children at 7.1%, which is half that of African American children. Children of color are more likely to live in neighborhoods with AAP levels that exceed the limits set by federal ambient air quality standards. Though vehicles are more fuel-efficient and there are tighter emission regulations, NO2 disparity related to air-traffic pollutants is still 37% higher in non-white populations. (Nardone, 2018).

During the Jim Crow era, African-Americans in Charlotte, NC were pushed to Charlotte's west side. This area is next to a major railroad line and the city's main industrial areas. As Charlotte developed from the 1960s to the 1980s, so did the highways. Three major highways are routed through Charlotte's west side, which are I-85, I-77, and NC-16. Historic redlining in 1935 caused black families to live in the northwest portion of the city, impacted the most by local pollution from traffic and industrial-permitted facilities. People living in this part of Charlotte face the disproportionate burden of living in pollution (Cupini, 2020). In a report by the American Thoracic Society, air pollution killed 24 Charlotteans in 2016. The deaths would not have happened if the city had more stringent air standards. The medical society states that the federal standard for ozone and fine particles are more lenient than it should be. Local cities such as Raleigh and Greensboro both had 14 deaths according to the report. Overall in North Carolina, 115 deaths were because of air pollution (Henderson, 2016).



DEMOGRAPHICS MAP



ZONING MAP OF CHARLOTTE, NC

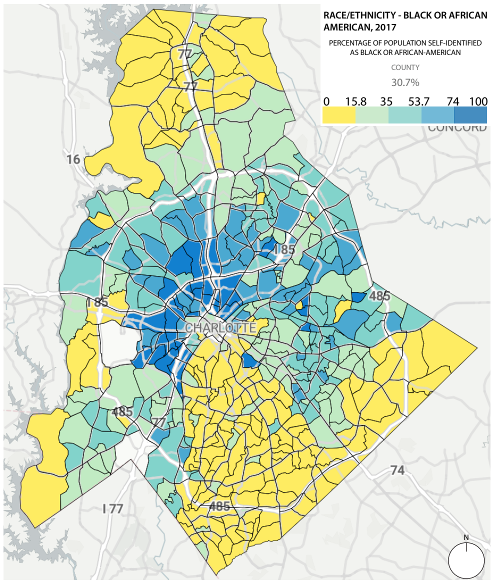


IMAGE A

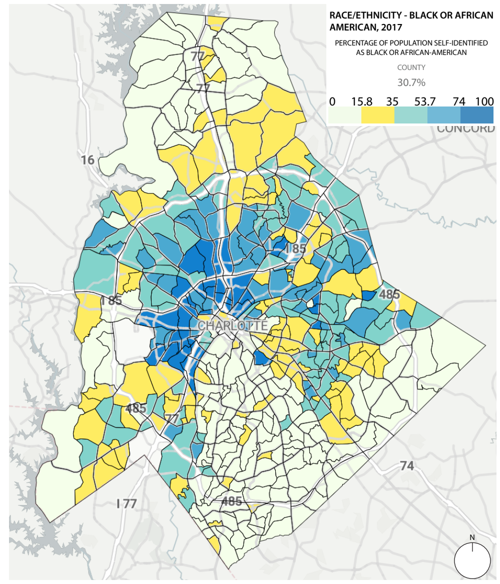


IMAGE B

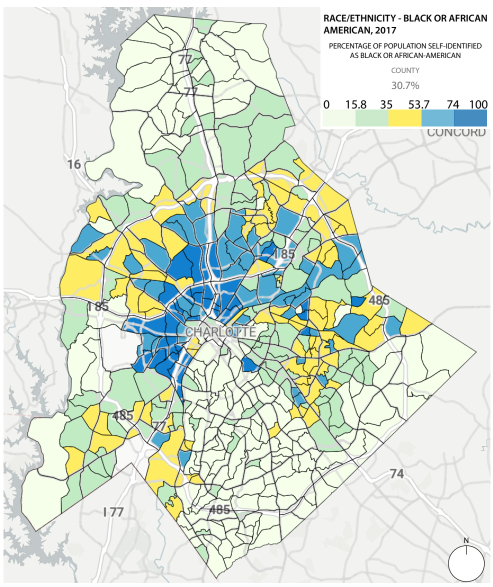


IMAGE C

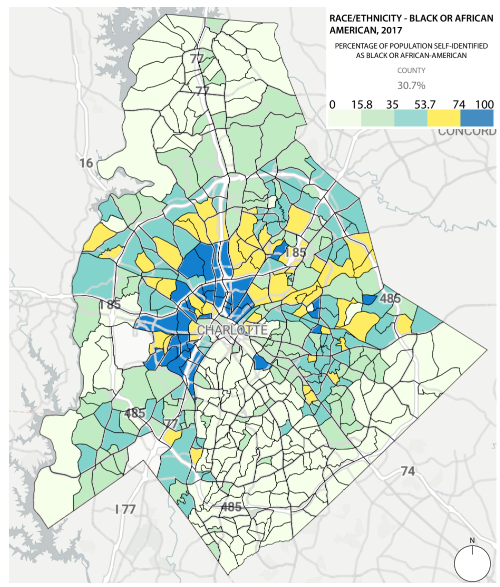


IMAGE D

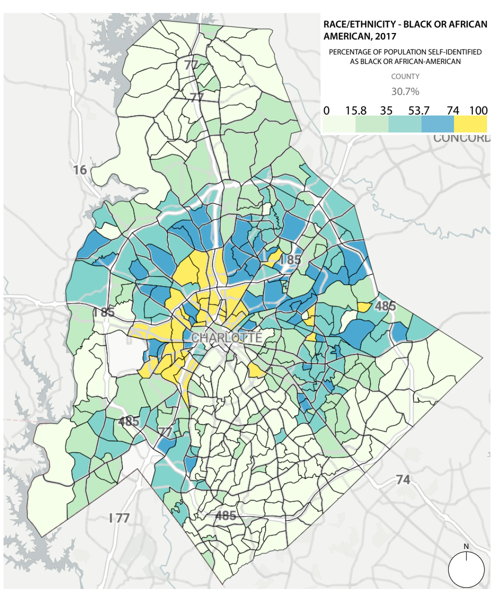


IMAGE E

THE VARIOUS MAPS SHOW WHERE THE CONCENTRATIONS OF AFRICAN AMERICANS ARE LOCATED WITHIN THE CITY OF CHARLOTTE.

PREDOMINATELY, AFRICAN-AMERICANS ARE CONCENTRATED ON THE WEST SIDE OF CHARLOTTE.

III. PROPOSED TECHNOLOGY

A. BACKGROUND INFORMATION OF TITANIUM DIOXIDE (TiO_2)

The proposed technology is a photocatalytic facade that uses the photocatalytic oxidation properties of titanium dioxide (TiO_2) (Mamaghani, 2021), while providing solar control and daylight illumination into the room. TiO_2 is a common additive in various food products, personal care, and consumer products. It is in candy, chewing gum, toothpaste, sunscreens, shampoo, deodorants, shaving creams, and paint. Its use is primarily due to the brightness, high refractive index, and resistance to discoloration (Weir, 2012). About 70% of TiO_2 produced is primarily used as a pigment in paint, but also used as a pigment in glazes, enamels, plastics, paper, fibers, pharmaceuticals, and cosmetics. Its use also goes beyond as it can have antimicrobial applications, catalysts for air and water purification, medical applications, and energy storage (Weir, 2012). Consumption of TiO_2 in food, use as consumer products, and household products are discharged as feces/urine, washed off of surfaces, or disposed of as sewage that enters wastewater treatment plants (Weir, 2012).

B. PHOTOCATALYTIC PROPERTIES OF TiO_2

The way TiO_2 works as an application to combat pollution can be addressed in the following study. “The degradation of photocatalytic technology can be summarized into four stages: photoexcitation, carrier capture, formation of radicals, and oxidation reaction. Compared with traditional catalytic technologies, photocatalytic technology has many advantages. First, reaction conditions such as sunlight, room temperature, and normal atmospheric pressure are common and easy to obtain. Second, the degradation processes and products of catalytic decomposition are pollution free, which are in line with the requirements of low-carbon environmental protection. Third, the characteristics of non-toxic, stable, low cost, and recyclable further promote development. The core of photocatalytic technology is the photocatalyst, and many materials can act as a photocatalyst” (Li, 2020).

C. TiO_2 USE IN ARCHITECTURE

Since the 1910s, TiO_2 has been used on buildings due to its excellent optical property (Guo, 2009). TiO_2’s photocatalytic property was observed in 1972 when examined to be a material used for air cleaning and sterilization. Since then, TiO_2 has been used as a material for air cleaning, sterilization, self-cleaning, anti-fogging, decoration, and building cooling (Guo, 2009). With this information, the use of TiO_2 continued to transform into various other beneficial applications, with one of them being in architecture.

As the application of TiO_2 showed to be beneficial, it was then used on buildings in the 1990s for the self-cleaning effect (Paolini, 2018). One of the buildings to take advantage of TiO_2 was the Marunouchi Building in Tokyo that opened in 2002 that featured one of the first buildings with self-cleaning glasses. Other buildings that used TiO_2 were the Jubilee Church in Rome in 2003 and the Hospital Manuel Gea González in Mexico City in 2013. The evolution of the product's use found itself to be used on facades for its self-cleaning and anti-pollution effects (Paolini, 2018).

MARUNOUCHI BUILDING TOKYO, JAPAN

JUBILEE CHURCH ROME, ITALY

HOSPITAL MANUEL GEA GONZÁLEZ MEXICO CITY, MEXICO

In terms of material selection, TiO_2 found its use for self-cleaning concrete. It is an innovative construction material by having concrete retain its light color and remove airborne toxins, particularly nitrogen oxides (Mircea, 2019). Because of the many uses concrete has from small items such as pottery, benches, stairs, walls, trash cans to large scale projects such as landscapes, facades, and buildings, the benefits of TiO_2 was now able to be used in many more aspects (Mircea, 2019). Thinking beyond the use TiO_2 could have in architecture, this thesis proposes a facade that uses the properties TiO_2 has to create a system that cleans the exterior air, but primarily focusing on the interior air for the occupants of the building. While providing solar control and daylight illumination into the room.

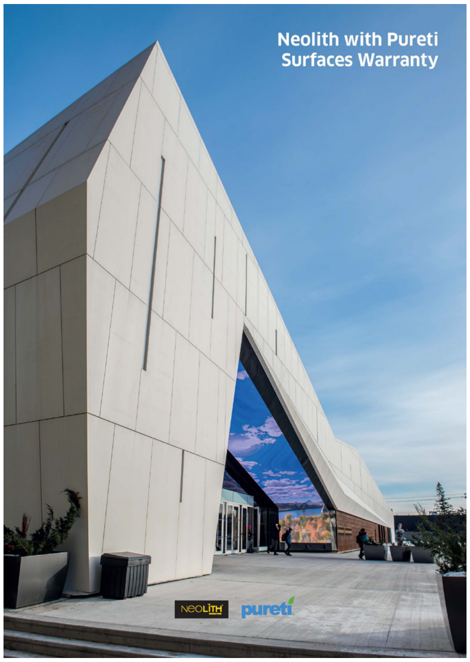
IV. PHOTOCATALYTIC FACADE PRECEDENTS

Many companies have been utilizing TiO2 for air pollution mitigation. These are a few precedents of how they use TiO2 to state how this proposed technology differs from others.

Pureti is an American surface treatment manufacturer. Their product uses a proprietary blend of TiO2 in a bottle form that allows the user to spray any surface and transform it into an "air cleaner." This product is sprayed on windows to activate the photocatalytic cleaning properties of TiO2 as a good temporary solution. Due to the necessary spray application, Pureti can only be used on smaller-scale projects. This solution seems to be an afterthought. A band-aid approach to a larger issue for the design and construction of a building with IAQ placed last on the list of priorities. For buildings that cannot afford a retro-fit, it seems like a cost-effective solution. This limitation makes the product not the most optimal to use for buildings with more surface area. Pureti understood this and teamed up with Neolith, a stone company that coats their stone with Pureti before installation.

VARIOUS PRODUCTS BY PURETI

Neolith is a Spain-based company that produces tiles on various scales for a building project. From kitchen countertops to facade panels. The company has teamed up with Pureti to have their facade panels act as air cleaners. One of their buildings, 570 Broom in New York, uses a panel by Neolith coated in Puerti. Because facades can take advantage of buildings' surface area, this decision enhances Puerti and Neolith's strength as companies. Neolith panels are typically solid, opaque materials that do not allow natural daylight into the space, limiting the potential for building energy saving costs. A benefit of the panel is that it acts as an exterior air cleaner. However, the exact range of this cleaning technology is unknown.

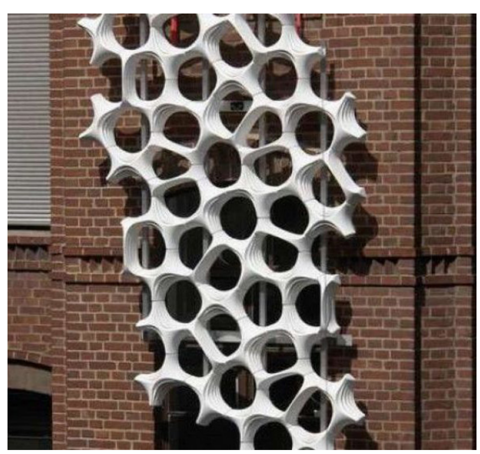


A COLLABORATION PROJECT BETWEEN PURETI AND NEOLITH

570 BROOM IN NEW YORK

Elegant Embellishments is a Berlin-based company that has developed a facade that uses TiO2 to eat the smog around it. One of their projects, Mexico City's Manuel Gea González Hospital, uses their design. The design allows for natural daylight into the space. However similar to Neolith, Elegant Embellishments' facade focuses on exterior air quality rather than IAQ, which is worst for most buildings. The exterior surface of the building gets the benefits. Though it is an idea with good intentions, its actual impact on the environment is questionable. How efficient can a single building with this facade improve the exterior air quality?

PROSOLVE370E IS A FACADE BY ELEGANT EMBELLISMENTS



FACADE USED AS A RETROFIT

V. FACADE PROPOSAL AND EXPERIMENTATION

A. FACADE BENEFITS

The design of the facade aims to achieve various benefits being a **cost-effective and low maintenance system**. TiO2 is durable against photo-corrosion, low toxicity, and low cost making it an efficient and applicable material (Shah, 2019). TiO2 has self-cleaning properties due to its hydrophilic features activated when irradiated with UV light that allow a very thin water layer to form on the surface. When UV is not present, TiO2 goes back to its hydrophobic state (Park, 2018). Because of these properties of TiO2, the facade is low-maintenance when it comes to cleaning. When TiO2 is exposed to sunlight, it reacts with water to generate hydroxyl radical, which breaks down organic molecules and microbes left behind on the surface. When it rains, the water spreads out on the hydrophilic properties of TiO2, washing away dust and dirt (Park, 2018). It requires no manual labor being a cost-efficient facade.

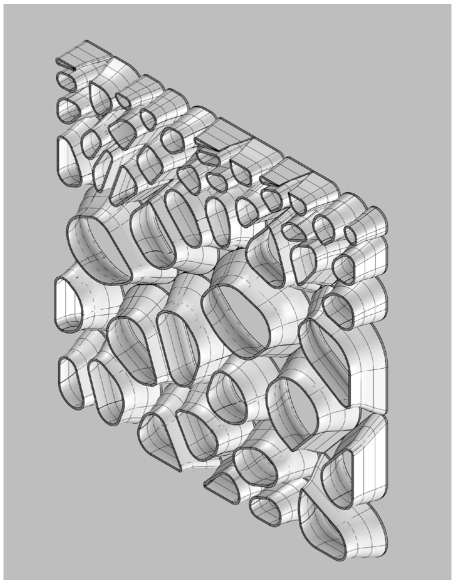
The facade is a **passive system to improve IAQ reducing VOCs, resulting in improved health and performance for the buildings' occupants**. Since most people spend most of their time indoors, IAQ is a concern as it can impact people's health and productivity (Shah, 2019). The facade would act as an air filter, cleaning the air before it enters the building. Various facade designs have incorporated it solely as an exterior idea, interior idea, and a double skin idea. VOCs removal is divided into two main groups: adsorption techniques and oxidation techniques (Shah, 2019). TiO2 is an oxidation technique that uses nano-semiconductor catalysts and the UV light from the sun to convert the organic compounds indoors to benign and odorless constitutions such as water vapor (H2O) and carbon dioxide (CO2) (Shah, 2019). It essentially takes the harmful products in the air and converts them into harmless byproducts.

The removal of VOCs are essential in any building. Occupants in an office building are one group of people who feel the effects. The effects of indoor environmental quality (IEQ) plays an important role in employee's health, well-being, and productivity (Singh, 2010). IEQ can negatively affect occupants' physical health, such as those who have asthma or respiratory allergies through poor IAQ, excess humidity, and insufficient ventilation (Singh, 2010). Studies show that employees with adverse health conditions working in a poor quality space are absent more, lose more work hours, and are less productive than employees with a healthier quality space (Singh, 2010). This impact on a building's occupants can also be known as sick building syndrome (SBS) (Joshi, 2008). The EPA defines SBS as “a situation in which the occupants of a building experience acute health- or comfort-related effects that seem to be linked directly to the time spent in the building. No specific illness or cause can be identified. The complaints may be localized in a particular room or zone or may be widespread throughout the building” (EPA, 2019a). Symptoms of SBS are: headaches, dizziness, nausea, eye, nose, or throat irritation, dry cough, impacts those with allergies, and develop flu-like symptoms (Joshi, 2008). More serious building-related diseases are: chest pain, shortness of breath, nosebleeds, cancer, pregnancy problems, and miscarriages (Joshi, 2008). Additional studies in evaluating an occupants’ health were done on employees who worked in a traditional office building and Leadership in Energy & Environmental Design (LEED) office building. LEED-certified buildings were found to provide a better quality space because of specific criteria. LEED-IEQ credits are defined to seven different attributes: “indoor air quality, temperature, humidity, ventilation, lighting, acoustics, and ergonomic design and safety” (Singh, 2010). Having a space that incorporates these different attributes is important to make the space more comfortable for the occupants.

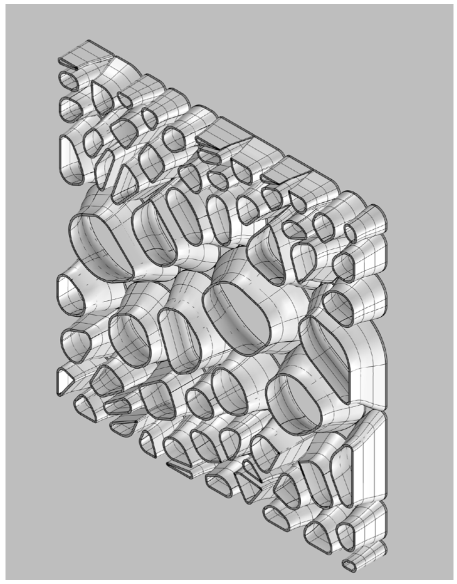
Because of the proposed design’s openness, it **provides solar control and daylight illumination into the room relying less on artificial light, resulting in savings on the energy consumption for buildings**. The importance of lighting within a space is stated by the Department of Energy, “lighting quality plays an essential role in the appeal and safety of interior and exterior spaces. Well-designed lighting systems can enhance productivity while glare and other harsh lighting features can decrease it. Light quality also affects sleep patterns and health and can shape the mood of any space. About 18% of U.S. electricity consumption and 6% of all U.S. energy consumption is used to provide indoor and outdoor lighting” (DOE, 2015).

B. DIGITAL PHASE

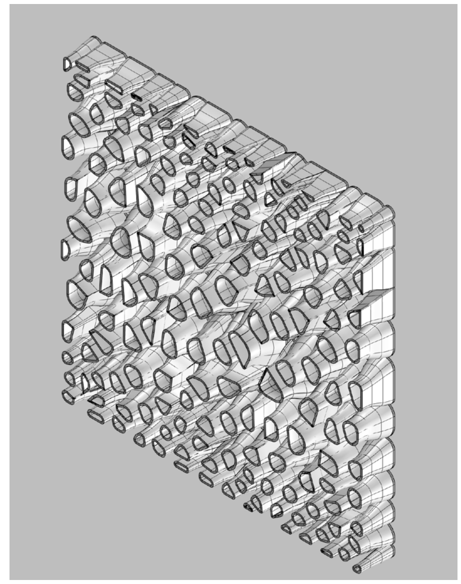
Development of the proposed facade was in collaboration with the Integrated Design Research Lab in the School of Architecture at the University of North Carolina at Charlotte. Part of the process for developing the facade was research, design, construction of the facades with 3D modeling software, and 3D models. The first step in the process were the various facade designs that balance between facade surface areas, solar control, daylighting penetration, and view-out. They are not final products, but different ideas of how this facade could be designed and integrated with TiO2. One of the facade iterations varied in the number of cells from 49 cells, 64 cells, and 169 cells. Two sets were then developed of uniform cells and varying cells. The benefit of the uniform cell design is that it allows for more surface area resulting in what is believed to be a more efficient reduction of NO2. The varying cell had different depths of cells that would allow more natural light into the space and a more open view.



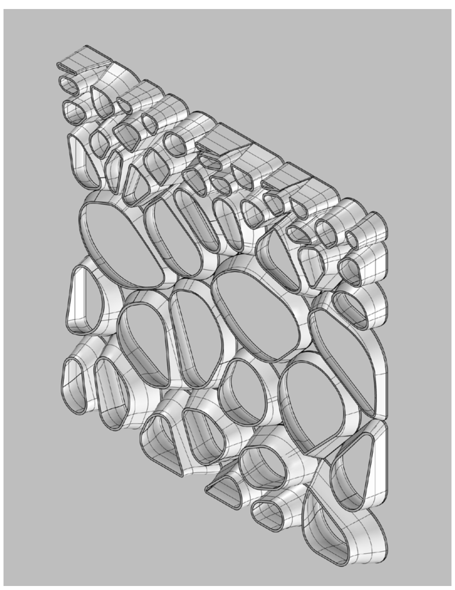
49 UNIFORM CELLS



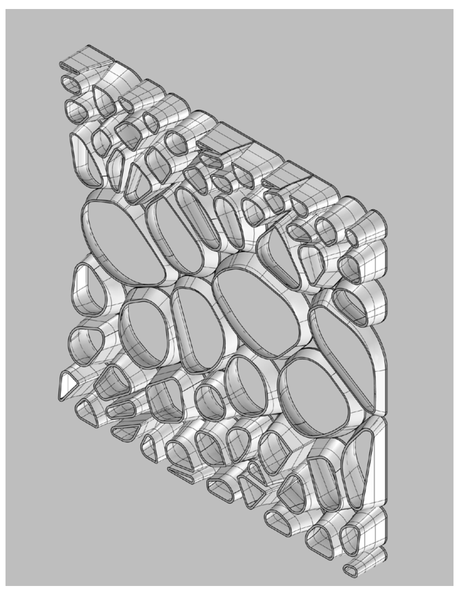
69 UNIFORM CELLS



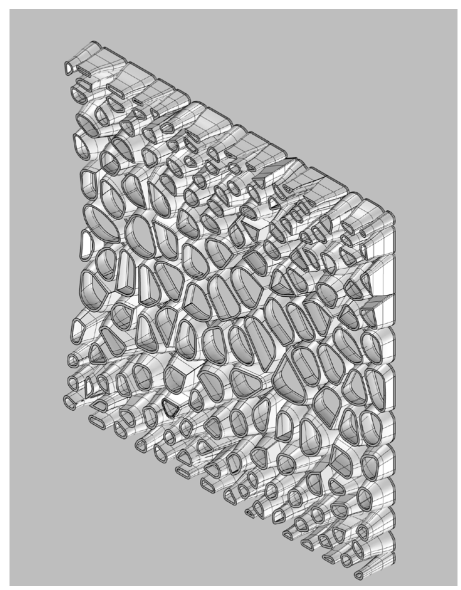
169 UNIFORM CELLS



49 VARYING CELLS



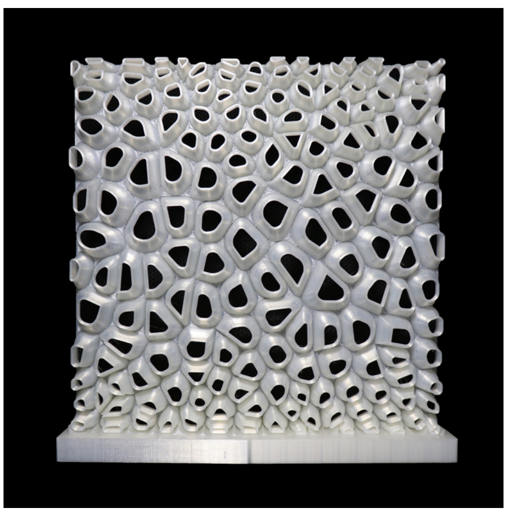
69 VARYING CELLS



169 VARYING CELLS

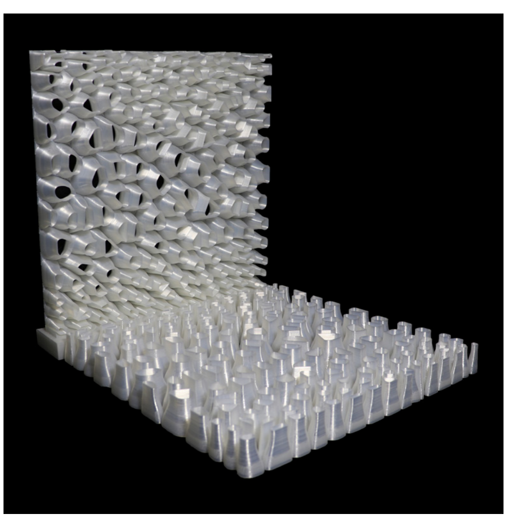
C. PHYSICAL MODELS

Once the facade's digital design was done, the next step was to fabricate the facade with 3D printers using polylactic acid (PLA). PLA as a material is favorable for the synthetic bio-based polyester that makes it zero toxicity, biocompatibility, high mechanical strength and thermal plasticity, and is compostable. It is made from materials that can be obtained from renewable sources such as starch (Karamanlioglu, 2017). For the facade's development, most of these features were not needed as the goal was to have physical representations to study and experiment with. However, using a sustainable material was considered not to develop waste in the process. Once the facades were 3D printed, documentation of the geometry, aesthetics, and lighting conditions were photographed to be studied. The entire model was printed at a 1'x 1' scale. Larger portions of the models were then printed at a 2' x 2' scale. The larger models were then coated with TiO2 to understand how applying TiO2 by hand would change the appearance of the model. Various coats were applied with an eyeball ratio of water to TiO2 that changed the mixture's viscosity from a paste to a water-like mixture. Additional physical representations were experimented. At the 2' x 2' scale model, two sets of models were printed. One that had no infill and one with infill. Infill is the interior structure and pattern of the model that can affect, weight, physical representation of the model depending on the transparency of the material used, print time, and flexibility.

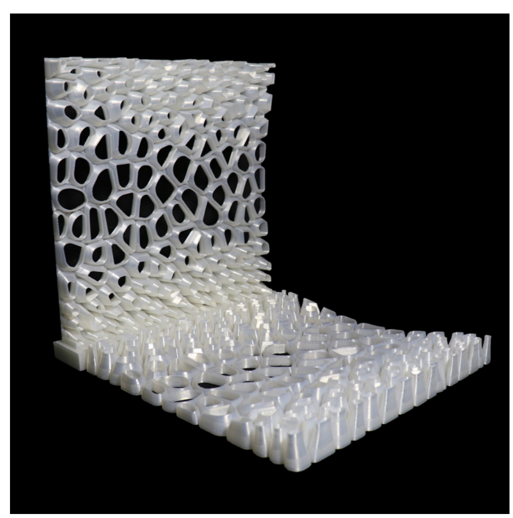


FRONT VIEW OF 169 UNIFORM CELLS

FRONT VIEW OF 169 VARYING CELLS



169 UNIFORM CELLS PERSPECTIVE VIEW



169 VARYING CELLS PERSPECTIVE VIEW

AN OUTDOOR STUDY OF THE 169 UNIFORM CELLS MODEL. AS MENTIONED, THE CELLS AT THE SAME DEPTH ALLOW MORE SURFACE AREA, BUT LIMIT THE VIEW.

AN OUTDOOR STUDY OF THE 169 VARYING CELLS MODEL. THE CELLS AT DIFFERENT DEPTHS, ESPECIALLY AT THE CENTER, ALLOW A MORE OPEN VIEW AT WHAT WOULD BE AVERAGE EYE LEVEL.

A THREE CELL STUDY MODEL OF THE PHYSICAL DIFFERENCE OF THE VISCOSITY OF THE TITANIUM DIOXIDE APPLIED TO A SINGLE CELL (TIO2). LEFT IMAGE HAS NO TIO2. MIDDLE IMAGE HAS A LIGHT AMOUNT OF TIO2 FROM A WATER-LIKE MIXTURE. RIGHT IMAGE HAS THE MOST TIO2 WITH A PASTE LIKE MIXTURE.

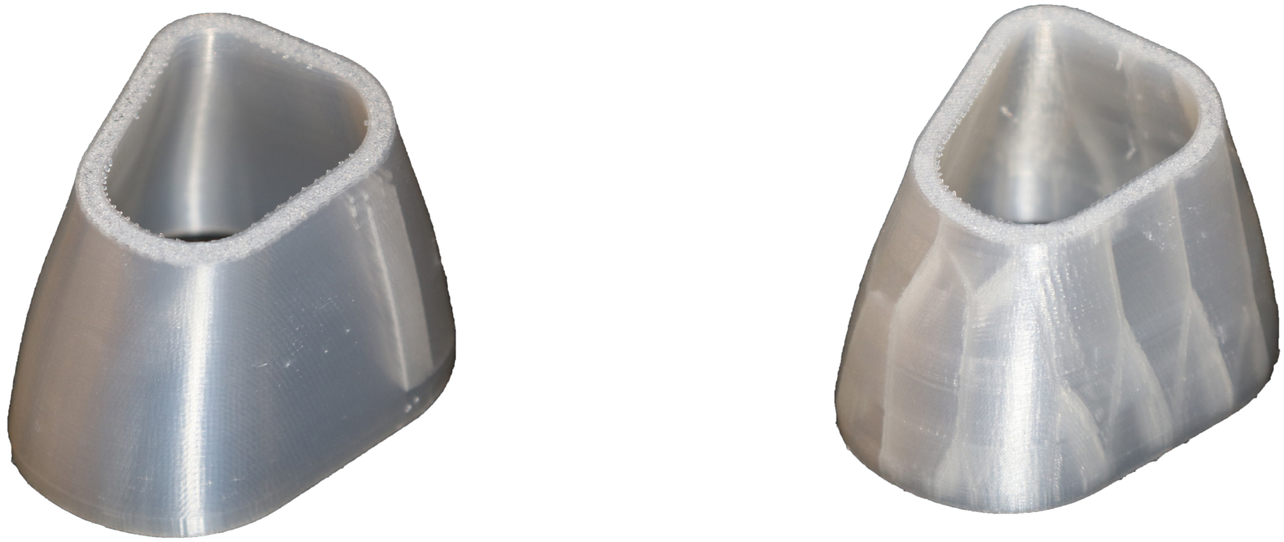
A SERIES OF CELLS WITH DIFFERENT AMOUNTS OF TIO2 APPLIED FROM THE LEFT HAVING NONE TO THE RIGHT HAVING THE MOST.

TOP OF MODEL / NO INFILL

BOTTOM OF MODEL / NO INFILL

TOP OF MODEL / WITH INFILL

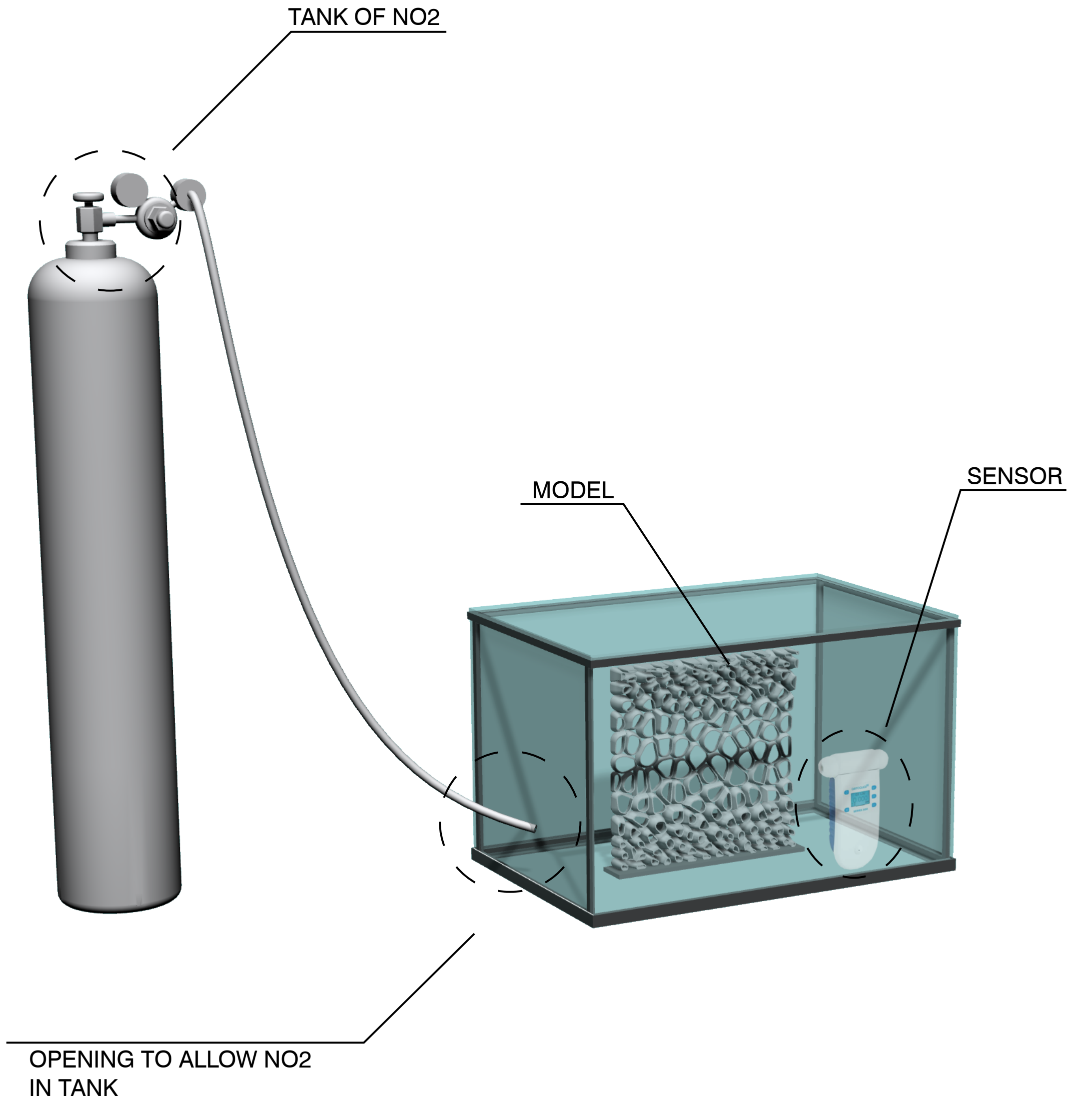
BOTTOM OF MODEL / WITH INFILL



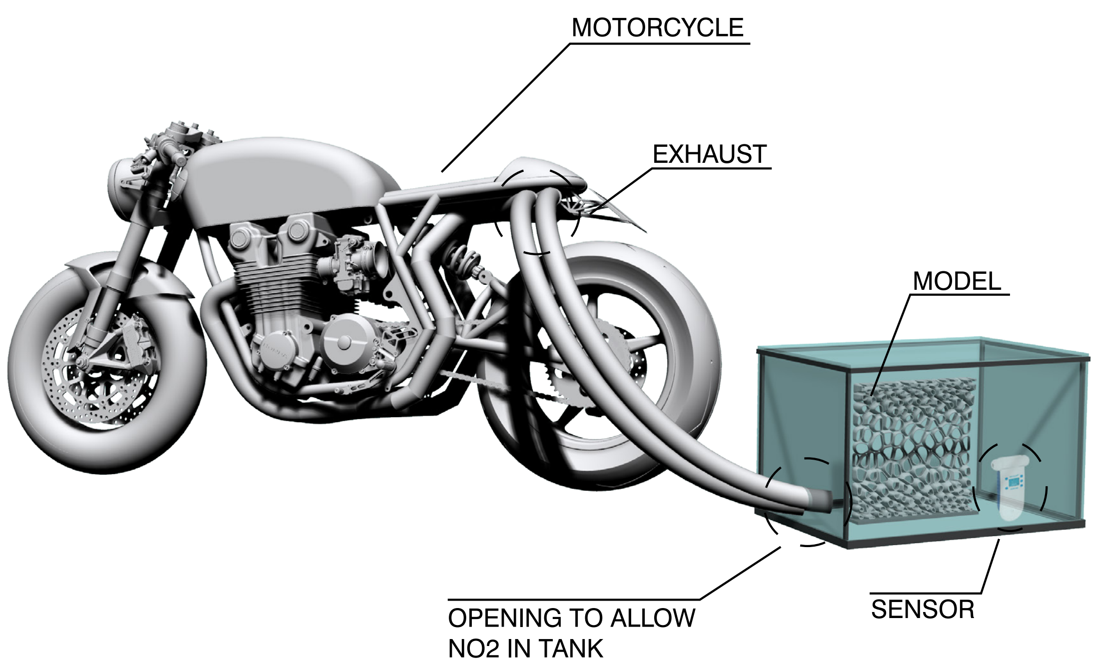
VISUAL COMPARISON OF AN INDIVIDUAL CELL WITH NO INFILL (LEFT) AND WITH INFILL (RIGHT). THE DIFFERENCE BETWEEN THE MODELS APART FROM AESTHETICS IS STRENGTH. THE MODEL ON THE LEFT IS FRAGILE WHEN PICKED UP. WHILE THE MODEL ON THE RIGHT IS STRONG. UNDERSTANDING FROM THE PREVIOUS STUDY MODEL EXERCISES, APPLYING TIO2 TO THE MODELS WILL COVER ANYTHING UNDERNEATH. WITH THIS IN MIND, A MODEL WITH STRENGTH WOULD BE BENEFICIAL IF CONDUCTING FURTHER STUDIES.

D. EXPERIMENT PREPARATION TO GATHER DATA

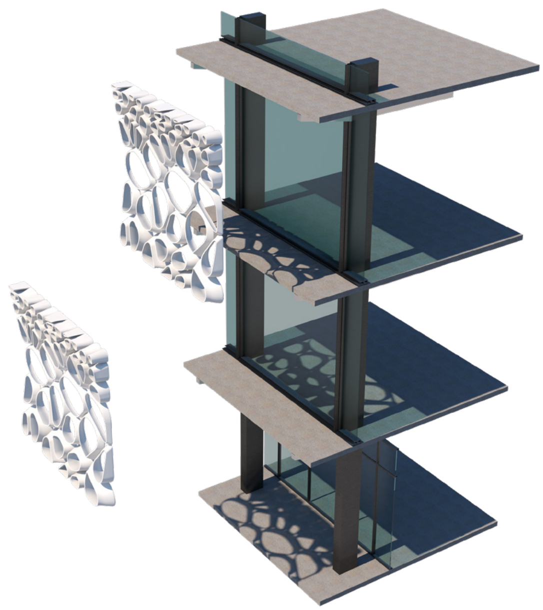
After the initial experiment process of getting the design into the real world, the next step was to think of how to gather data on the reduction of NOx the facade provides. Several ideas were developed. The first step was to design and create an enclosure that could house the facade coated with TiO2. The enclosure would need to be airtight to then fill with NO2. A bluetooth/wifi NO2 sensor is needed to gather the data digitally on how much of a reduction happens within the enclosure. The cost of the experiment did factor in. The goal is to try and make this as economical as possible, but also informative. Before working with high quality sensors, a lot of DIY ideas were explored and are currently in development. DIYs of creating our own sensor from various parts. This does not provide extreme precision, but allows us to see a relative NO2 reduction. Next is to generate our own NO2 source for experimentation. We can fill the enclosure from the fumes of the exhaust using a lab member's motorcycle or a tank of NO2. Additional ideas are being proposed whether to have a valve system to control the release of air and NO2 into the enclosure. And whether additional openings on the enclosure should be considered to have the power needed for the LED to activate the TIO2 from an outlet. Current discussions are leaning more towards a solar-powered portable charger that can minimize the openings in the enclosure and provide a continuous source of power.



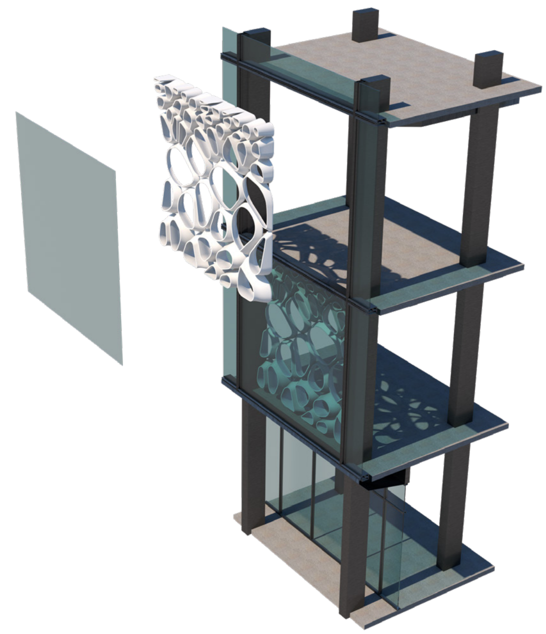
EXPERIMENT RENDER ONE



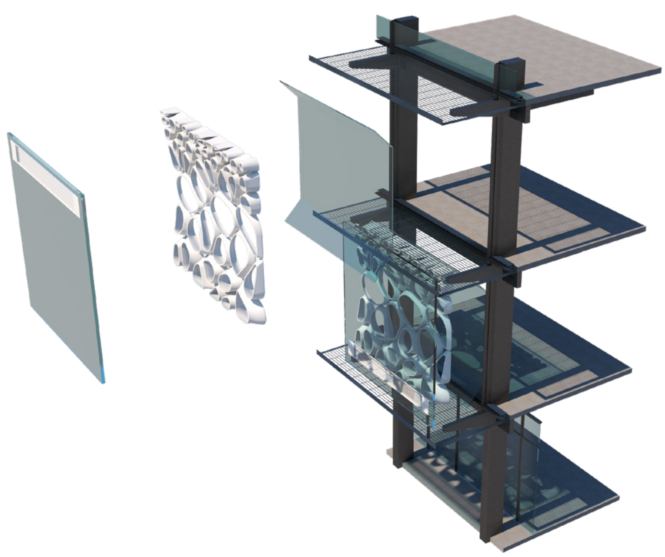
EXPERIMENT RENDER TWO



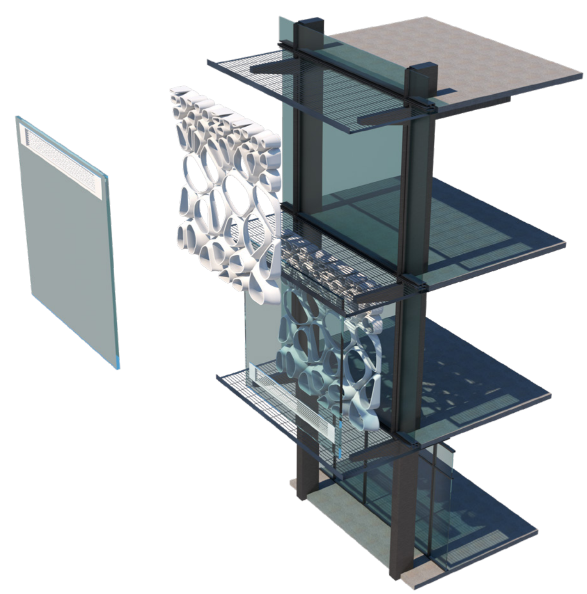
SINGLE FACADE + EXTERIOR PHOTOCATALYTIC DEVICE



SINGLE FACADE + INTERIOR PHOTOCATALYTIC DEVICE



DOUBLE SKIN FACADE + PHOTOCATALYTIC DEVICE IN THE CAVITY (SPRING/FALL)



DOUBLE SKIN FACADE +PHOTOCATALYTIC DEVICE IN THE CAVITY (SUMMER/WINTER)

VI. CONCLUSION

Air pollution is an ongoing issue many people face in the world. According to the World Health Organization (WHO), nine out ten people breathe air containing high levels of pollutants (WHO, n.d). WHO estimates that 7 million people die every year from exposure to air pollution (WHO, n.d). It is believed that the 4.2 million deaths that occurred in 2016 were because of ambient air pollution, while 3.8 million deaths were caused by household air pollution (WHO, n.d). Low and middle-income countries are affected the most (WHO, n.d).

Despite that the United States is a first-world country, low-income communities, particularly people of color, were impacted the most in the United States. Predetermined factors such as redlining continue to affect the current generation of low-income minorities. Despite creating the least amount of pollution compared to the white population, POCs are the ones who suffer the most. POCs are affected in terms of finances from unplanned medical visits. And children of color having low academic performance from the absence of school due to the unplanned medical visits (Nardone, 2018).

From various peer-reviewed studies, people's health within a building is affected by indoor environmental quality relating to occupants' health and productivity. Such as POCs living in neighborhoods with close proximity to factories emitting emissions (EPA, 2016b). The American Psychological Association (APA) have found that high levels of air pollution may damage children's cognitive abilities, increase adults' risk of cognitive decline, and even contribute to depression (Weir, 2012).

Lastly, the type of facade used on a building will contribute to the amount of energy needed for lighting use and thermal comfort. As stated earlier, about 18% of U.S. electricity consumption and 6% of all U.S. energy consumption is used to provide indoor and outdoor lighting" (DOE, 2015). Supplying natural daylight into a space and controlling the solar glare will decrease the need for artificial light while improving occupant comfort. The type of facade used on a building will determine the energy performance of a building and the level of sustainability (Planas, 2018).

The proposed technology compared to what is currently available allows the facade to provide multiple benefits. The technology focuses on being an exterior element of a building that impacts the building's occupants and building performance. The facade aims to create a sustainable impact on the environment, people, and buildings by reducing pollution and saving energy. Its design consideration and material application will create a better quality space for everyone.

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