Paper ISAIA

by Magister Arsitektur

Parametric Facade Module to Optimizing Titanium Dioxide Photocatalysts at the Parking Building

Daniel Alison[1], Agus Dwi Hariyanto[2]

[1]Alumnus, Master of Archicture Study Program, Petra Christian University
[2]Asisstant Professor, Petra Christian University

Abstract

The demand for parking buildings is unavoidable in big cities due to space limitations. However, parking buildings might be notorious contributors to polluting the environment. The vehicles produce significant gas pollution, reducing air quality when released into the neighborhood. Using Titanium Dioxide (TiO_2) coating on facades can be an alternative solution for reducing pollution with low installation and maintenance costs. This research aims to identify facade designs that can optimize the potential of TiO_2 photocatalysts in reducing the pollutants produced by the vehicles inside the building. The quantitative research method was carried out through simulation using parametric modeling. The case study was the parking building of Joyoboyo Terminal in Surabaya. The simulation was conducted to determine the façade design, identify the intensity of solar radiation on the facade, and evaluate the airflow rate through the facade. The results showed that the angle at which façade modules received the highest intensity of solar radiation was 15 deg. Meanwhile, the curved shape of façade modules had a larger surface area exposed to solar radiation. The curved shape did not intercept the airflow into the building but reduced the airflow speed from indoors to outdoors. This result was considered beneficial because slowing down the indoor and outdoor airflow can maximize the photocatalyst process on the façade.

Keywords: Parametric Design, Titanium Dioxide Photocatalyst, Parking Building Facade.

1. Introduction

The increase in urban population impacts the rise in motorized vehicles. Data from 2015-2017 in all districts and cities in East Java shows that the most significant increase in motorized vehicles was in Surabaya (Priyambodo, 2018). The increasing need for parking facilities and limited land has triggered the construction of parking buildings to solve the problem of parking space requirements in urban areas. However, if we look at it from an environmental aspect, the existence of a parking building with motorized vehicles contributes to exhaust gas pollution for the surrounding environment (Arrasyid, 2021). Parking areas are places where motorized vehicles pass, which is the leading cause of pollution in urban areas, and most buildings in urban areas have open and closed parking structures (Nasrul, 2021).

In general, parking buildings focus on function and space requirements, which impact the impression of a rigid parking building (Arrasyid, 2021). With current developments, parking space is not just a function and space efficiency but can also have added value in an urban context and as an expression of urban space. The facades can become landmarks in the urban landscape that can improve environmental quality by managing the architectural design of parking building facades (Sherzad et al., 2022). The idea of reducing carbon emissions and improving air quality through architecture in parking buildings continues to develop, both actively through technology and passively in processing facade designs on buildings.

Approaches with active and passive systems can reduce vehicle emissions from inside the parking building to outside the environment. The passive approach is more profitable because it can reduce pollutants in the air with low-cost installation costs and minimal maintenance (Yamuna Sakthivel, 2019 1 One of the developments in passive systems is the application of photocatalysts such as Titanium Dioxide (TiO_2) in the form of nanoparticles in building materials which can reduce the concentration of specific pollutants in the surroundings, such as nitrogen oxides and volatile organic compounds. This material can be easily applied to building facades where the material has two main properties, namely de-soiling, namely a self-cleaning material so it requires minimal maintenance and de-polluting properties as a pollutant

Contact Author: Agus Dwi Hariyanto, Asistant Professor, Petra Christian University, address: Jl. Siwalankerto 121-131 Surabaya
Tel: +62 31 8439040 Fax: -
e-mail: adwi@petra.ac.id

breaker in the air (Maggos et al., 2007). The application of Titanium Dioxide (TiO_2) coating on building facades has been carried out at the Manuel Gea Gonzalez Hospital, Mexico City, where the building has a facade coated with titanium dioxide (TiO_2). This layer helps break down pollutants when exposed to light by releasing free radicals. Materials coated with this substance can be used on any surface so they can be applied to the facade of a parking building.

Titanium dioxide (TiO_2) photocatalyst has excellent pigment characteristics, high UV absorption, and catalyst stability, making it most suitable for applications in large-scale purification (Saravanan et al., 2017). Photocatalysts based on titanium dioxide (TiO_2) are attractive because they can quickly break down pollutant compounds in polluted air and wastewater (Hashimoto et al., 2005). Various conditions influence the performance of photocatalysts in pollutant degradation in urban environments, including the UV radiation that occurs, wind contact speed, relative humidity, and material properties such as the type of layer and substrate applied (Sakthivel, Y. 2019). Surface expansion and creating turbulence to slow airflow on the façade surface are two strategies considered effective in improving the performance of titanium dioxide (TiO_2) based photocatalysts applied to building façades to break down pollutants.

The higher the pollutant concentration on the photocatalyst surface, the less effective the passive pollutant breaker will be. The higher the UV radiation will be received if the surface area is more significant with the appropriate orientation. Therefore, it is essential to design photocatalyst surfaces with higher surface areas (Sakthivel, Y., 2019). Flow rate is the volume of fluid flowing per unit time over a surface. The flow rate of pollutants to the photoreactor greatly influences the uptake and degradation of pollutants. The higher the flow rate, the less time pollutants remain on the photoreactive surface. An increase in the photocatalytic rate can be seen in how long the pollutant stays on the photoreactive surface (Ibhadon & Fitzpatrick, 2013). It is an essential aspect of facade panel design in reducing air velocity and providing pollutants with a more extended period of contact with the panel surface. The type of material that is suitable for TiO2 to stick evenly is material with a cement surface (Arisky, 2022)

This research will focus on discussing facade modules that can increase the potential of TiO_2 as a photocatalyst to break down pollutants. Unlike previous research, where the source of pollutants was in the environment, this research focuses on sources of pollutants inside the parking building, where the facade was designed to reduce pollution from vehicle emissions that escape into the environment. Hopefully, this research can help overcome the problem of air pollution in cities as part of sustainable architecture that applies the principles of urban ecology to maintain a sustainable living ecosystem so that future generations can enjoy it.

2. Methods

2.1. Types and Stages of Research

This type of research is quantitative, with experimental methods using simulations on building facade modules to optimize solar radiation and obtain pollutant turbulence on facade modules. The stages in the simulation include:

- Simulate the capture area and maximum angle to sunlight.
- Simulate the facade module's shape in the capture area, which can maximize the flow of air pollutants toward the outside of the facade facing the sun.

The facade module's shape simulation uses Rhinoceros 3D and Grasshopper software to create facade modules. Solar radiation simulation using the ladybug plug-in and airflow simulation using RhinoCFD. Figure 1 shows the framework study.

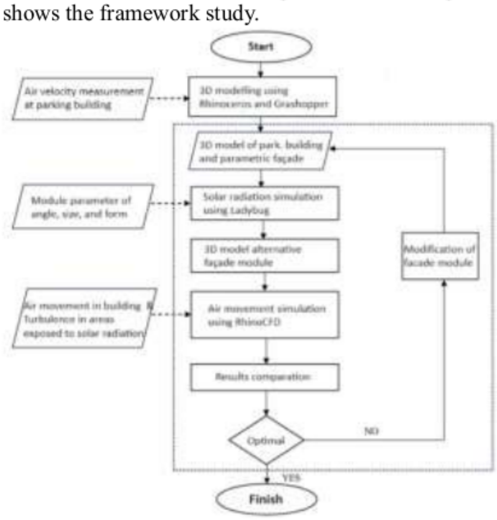


Fig. 1. Framework of Study

2.2. Case Study: The Parking Building of Joyoboyo Terminal in Surabaya

Joyoboyo Surabaya Terminal is close to Wonokromo Railway Station, Surabaya Zoo, and Darmo Trade Center (Fig. 2). The consideration for selecting the Joyoboyo Terminal Parking Building as a case study is that its function is to accommodate parking for various modes of public transportation at the terminal and for visitors to the Surabaya Zoo. Apart from that, the building has a green building concept that uses a green vertical facade that also aims to reduce air pollution, although its effectiveness has yet to be proven. This parking building has an orientation facing north-south. In contrast to the south side, the north side has continuous sunlight throughout the day. The conditions on the north side can help improve the photocatalyst process in TiO_2 material. Apart from that, on the north and south sides of the Joyoboyo Surabaya Intermodal Terminal building, no buildings are above two floors, making airflow unobstructed and able to flow well. For this reason, the north side was chosen as the research object.

Fig. 2. Joyoboyo Intermodal Terminal, Surabaya

3. Result and Discussion

The TiO_2 facade module is placed above the parapet wall with opening dimensions of 2100mm x 7300mm, where the axle distance between columns is 8000mm, with column dimensions of 700mm x 700mm, and parapet height is 1200mm. A plane is created from these openings, and the facade module will fill that. With the grasshopper parametric method, a base area measuring 2100mm x 7300mm is the first thing to be created. The flat area is divided based on a 200mm x 200mm grid to produce a 2000mm x7200mm area with an offset of 50mm around the frame for the TiO_2 facade module.

3.1. Solar Radiation Simulation

Solar radiation analysis for one year on the 3D model of the case study parking building was carried out using the Ladybug plug-in. The building is the context, while the 7300mm x 2100mm opening is the geometry to be analyzed (Fig. 3).

Fig. 3. Context (Red) and geometry (Yellow) of the Joyoboyo Intermodal Terminal Parking Building

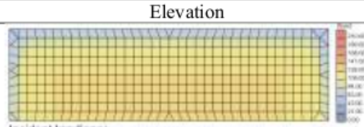
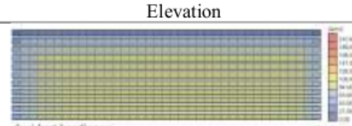
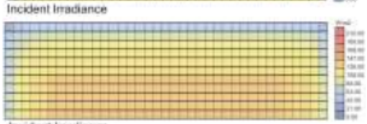
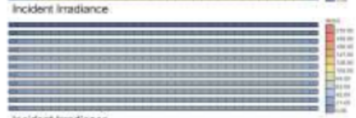
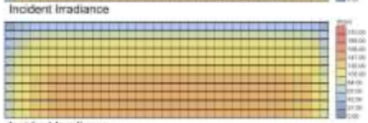
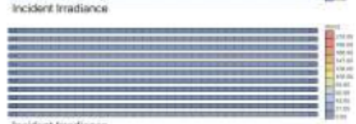
North – West side (left), South– East side (right), of the Joyoboyo Intermodal Terminal Parking Building

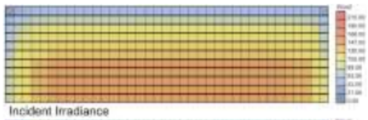
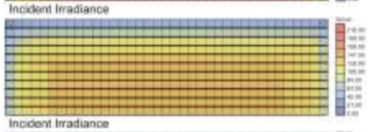
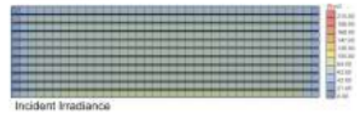
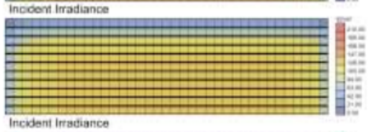
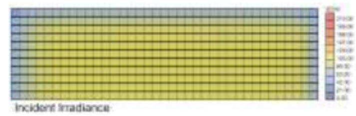
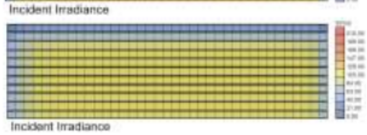
Fig. 4. Analysis solar radiation North side (Top), South (Middle), West side (Bottom Left), East side (Bottom Right)

From the solar radiation data, the north side is the side that has a high intensity of solar radiation, namely 147-210 W/m2, while the south side is the side that has a moderate intensity of solar radiation, namely in the range of 105-126 W/m2 (Fig. 4). The west and east sides have a high intensity of solar radiation. Still, they are partially covered by neighboring buildings, so the west and east sides are not fully exposed to solar radiation. Therefore, the researchers chose the south side façade to study the parametric TiO2 façade module because it considers the side with the minor radiation compared to the other sides to solve the problem.

Simulation of solar radiation on the TiO_2 parametric facade module begins by connecting the facade module script from Grassopher with the Ladybug script. The parameters in the Grasshopper script in the form of angle, module distance, and module shape will be parameters for obtaining alternatives in the design. The researcher assessed the module based on how optimal the module is in capturing solar radiation in the TiO_2 photocatalyst process. The simulation results can be seen in the table 1.

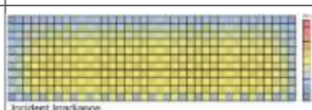
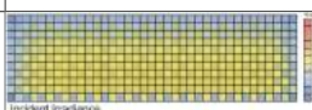
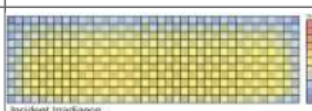
Table 1. Simulation of the optimal angle of sunlight.

Angle	Elevation	%	Angle	Elevation	%
0°		100 %	45°		71%
5°		105 %	60°		58%
10°		106 %	120°		1%

15°		112 %	135°		62%
20°		107 %	150°		64%
25°		105 %	165°		92%
30°		90%	175°		93%

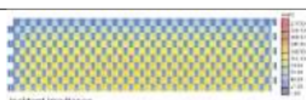
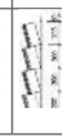
From Table 1 angle of 15° is the largest angle for receiving solar radiation with an increase in the intensity of solar radiation of 12% from the initial condition without an angle.

Table 2. Simulation of the module distance.

Angle	Elevation	Sec	%
15°			94 %
15°			96 %
5°			94 %

Simulation of the module distance (Table 2) is to try to split the panels on an odd-even basis to provide depth in the facade area as an alternative to two facade modules. The results of the simulation can be seen that an angle of 15° with close spacing between panels has optimal solar radiation intensity.

Table 3. Simulation of the module shape.

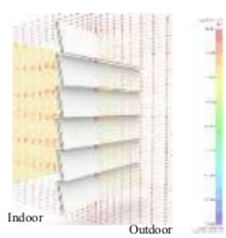
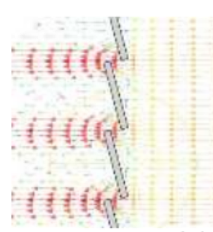
Angle	Elevation	Sec	%
0°			69 %
15°			65 %
15°			94 %

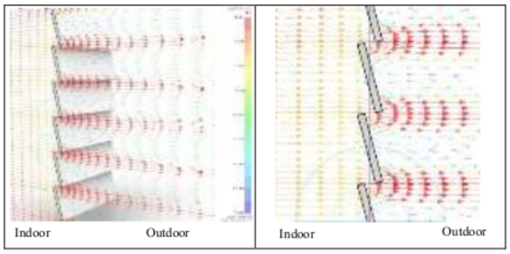
From table 3 The results of simulations can be seen that the front of the facade with an angle of 15° and the rear with a box shape without corners have optimal solar radiation intensity.

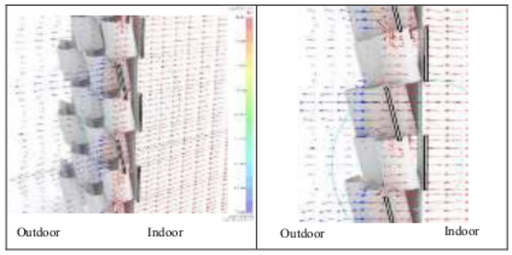
3.2. Air Flow Simulation

Airflow simulations were conducted on three modules with the best solar radiation intensity. The first module's simulation results are that the airflow speed entering the parking building slows down by 24%. The speed of airflow leaving the building also slowed down by 24%. The horizontal airflow is less able to hit the outside of the facade, so photocatalytic activity does not occur in the horizontal airflow. In vertical flow, there is micro movement on the outside of the facade, where there is a slowdown of 75% (see Table 4).

Table 4. Facade Alternative Air Flow Simulation Module 1

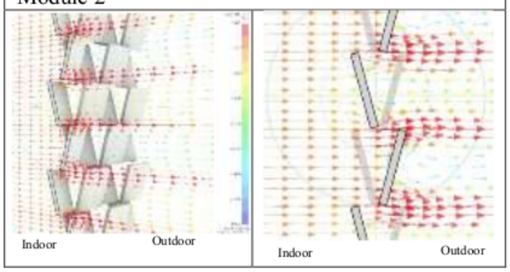
 Indoor Outdoor	 Indoor Outdoor





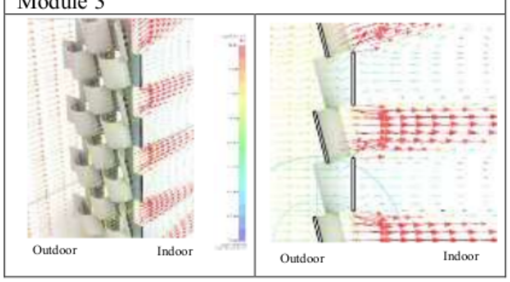
The second module's simulation results show that the airflow speed entering and leaving the parking building has slowed by 36%. The horizontal airflow hits the outside of the facade with a deceleration of 72.4%. In vertical air flow, there is micro movement on the outside of the facade, where there is a slowdown of 75% (see Table 5).

Table 5. Facade Alternative Air Flow Simulation Module 2



The third module's simulation results show that the airflow speed entering the parking building has slowed down by 11.5%. The speed of airflow leaving the building slowed down by 96.5%. The horizontal airflow hits the outside of the facade well so that photocatalyst activity is maximized. In vertical air flow, there is micro movement on the outside of the facade, where there is a slowdown of 75% (see Table 6).

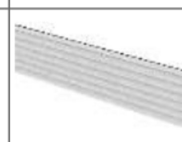
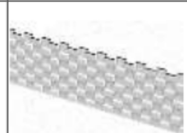
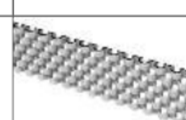
Table 6. Facade Alternative Air Flow Simulation Module 3



3.3. Comparison of Three Facade Module Alternatives

The first module has the largest solar radiation capture area compared to the other two. However, when analyzed using air movement, there is no gap for horizontal airflow, so the first module can less maximize TiO2 photocatalyst activity. The second module has a solar radiation intensity of 96%, in contrast to the third module, with solar radiation of 94%. However, if you look at the air flow entering the building, the third module is the most optimal alternative, as the air flow entering the parking building does not slow down much. Apart from that, the most significant slowdown in airflow on the part of the front facade facing the sun occurs in the third module. The slow down airflow of pollutants on a surface coated with TiO2 is necessary in the TiO2 photocatalysis process. From the analysis above, the third module is the optimal alternative facade module in the TiO2 photocatalyst process for breaking down pollutants inside the parking building and allowing them to flow out of the building. A comparison of the modules can be seen at Table 7.

Table 7. Comparison of 3 Model

Alt	Modul facade	Intensity Solar radiation	Reducing Air Flow indoor	Reducing Air Flow Horizontal outdoor	Reducing Air Flow Vertical outdoor
1		**112 %**	24%	0%	**75%**
2		96%	36%	72.4%	**75%**
3		94%	**11.5 %**	**96.5%**	75%

4. Conclusions

The independent variables that are the focus of this research are the intensity of solar radiation and the airflow rate on the facade exposed to sunlight. Meanwhile, the fixed variable is the type of cement-based support material where the TiO_2 photocatalyst can react well with cement-based materials. Apart from that, the layer thickness was set at 1mm because several studies stated that the 1mm layer had the maximum photocatalytic reaction compared to 3mm and 5mm.

From the independent variables, light intensity and air flow rate can determine the effective angle and shape of the module for the application of the TiO_2 photocatalyst. The results of the simulation regarding

the intensity of solar radiation using the ladybug plug-in at the Joyoboyo Terminal parking building in Surabaya are:

a. The side of the building that gets the most solar radiation is the north side, while the south side has the lowest intensity of solar radiation.
b. The angle with the highest intensity is at an angle of 15°. Apart from that, there is also a shading simulation experiment on the north side of the building; an angle of 15 ° can allow the maximum sun to enter at 11.00-15.00, where the intensity of sunlight entering through the facade module is between 10-30%.
c. The curved module shape has a larger cross-sectional area exposed to solar radiation than the flat square shape.
d. The rectangular panels on the facade are made with holes to let in sunlight and give parking building users a visual impression of transparency.

The results of the simulation regarding airflow passing through the facade module and hitting the side exposed to sunlight using RhinoCFD simulation in the Joyoboyo Terminal parking building are:

a. The facade, which consists of two layers of panels (front-back), has an airflow that is exposed to the outside of the facade horizontally and vertically. Meanwhile, a facade with one layer of panels only has vertical airflow that is exposed to the outside of the facade.
b. The simulation results show that the curved module does not hinder the flow entering the building but slows down the airflow leaving the environment, where slowing the airflow on the outside of the facade can maximize the TiO_2 photocatalyst process.

5. References

1) Arisky, T. N. (2022) Perbandingan Degradasi Methylene Blue (Mb) dan Methyl Orange (Mo) Menggunakan Titanium Dioksida (TiO_2) Terlapis Pada Permukaan Semen. Undergraduate Thesis, Universitas Islam Indonesia Yogyakarta. https://dspace.uii.ac.id/handle/123456789/39386
2) Arrasyid, W. H. & Wicaksono, R. (2021). Kajian Desain Gedung Parkir Dengan Konsep Arsitektur Ekologi Sebagai Fasilitas Penunjang Objek Wisata Pasar Lama, Kota Tanggerang, Banten, Undergraduate Thesis, Institut Teknologi Indonesia, .http://repository.iti.ac.id/jspui/handle/123456789/997
3) Hashimoto, K., Irie, H., & Fujishima, A. (2005). TiO 2 Photocatalysis: A Historical Overview and Future Prospects. Japanese Journal of Applied Physics, 44(12R), https://doi.org/10.1143/JJAP.44.8269
4) Ibhadon, A., & Fitzpatrick, P. (2013). Heterogeneous Photocatalysis: Recent Advances and Applications. Catalysts, 3(1), 189–218. https://doi.org/10.3390/catal3010189
5) Maggos, Th., Bartzis, J. G., Liakou, M., & Gobin, C. (2007). Photocatalytic degradation of NOx gases using TiO_2-containing paint: A real scale study. Journal of Hazardous Materials, 146(3), 668–673. https://doi.org/10.1016/j.jhazmat.2007.04.079
6) Nasrul, Nasrul (2021) Kualitas Udara pada Gedung Parkir (Studi Kasus: Gedung Parkir Menara Bosowa Makassar). Undergraduate thesis, Universitas Hasanuddin. http://repository.unhas.ac.id:443/id/eprint/18313
7) Priyambodo, P. (2018). Analisis Korelasi Jumlah Kendaraan dan Pengaruhnya Terhadap PDRB di Provinsi Jawa Timur. Warta Penelitian Perhubungan, 30(1), 59. https://doi.org/10.25104/warlit.v30i1.634
8) Saravanan, R., Gracia, F., & Stephen, A. (2017). Basic Principles, Mechanism, and Challenges of Photocatalysis. In M. M. Khan, D. Pradhan, & Y. Sohn (Eds.), Nanocomposites for Visible Lightinduced Photocatalysis (pp. 19–40). https://doi.org/10.1007/978-3-319-62446-4_2
9) Sakthivel, Y. (2019) Urban Facade: Photocatalytic Building Envelope for Passive Remediation of Air Pollution. Master Thesis Delft University of Technology.
10) Sherzad, M., Arar, M., & Jung, C. (2022). The Analysis of the Evolution of Parking Garage Façade as a Communicative Interface. International Journal of Advanced Research in Technology and Innovation. https://doi.org/10.55057/ijarti.2022.4.4.4

Paper ISAIA

ORIGINALITY REPORT

4%	0%	1%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to TU Delft Student Paper	4%

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		