





Exploring and defining flats geometry for minimizing dust

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ARTICLE INFO	ABSTRACT
<p><i>Article history:</i> Received January 06, 2022 Received in revised form April 01, 2022 Accepted July 12, 2022 Available online August 01, 2022</p> <p><i>Keywords:</i> Design Dust Flats Geometry Wind</p> <p>*Corresponding author: Rizka Tiara Maharani Department of Architecture, Faculty of Architecture and Design, UPN Veteran Jawa Timur, Indonesia Email: rizka.tiara.ar@upnjatim.ac.id ORCID: https://orcid.org/0000-0003-1379-2724</p>	<p><i>Residential houses such as flats located near industrial areas are vulnerable to the threat of high-intensity dust, thereby, exposing the occupants to Sick Building Syndrome (SBS) in the form of health problems, especially in the upper respiratory system. Therefore, this research was conducted to find appropriate design solutions to minimize dust from entering buildings through the application of geometric planes as a form of defense. It is also important to note that dust is closely related to the direction of the wind which is its conveying medium. This led to the determination of the right geometric shape to be applied as a dust barrier in the building facade. Moreover, this research was based on the force-based framework which proposes a form-refine-assembly stage consisting of several methods to determine the shape through simulation and evaluation associated with existing theories. The results were able to determine the position and shape of the facade area to serve as the barrier to the arrival of dust. The design is expected to be integrated into the shape and landscape layout of buildings to reduce dust in the site area.</i></p>

Introduction

Dust is one of the components interfering with the comfort of occupants in residential houses such as flats, especially those located near industrial areas. Its effect is associated with certain symptoms such as upper respiratory disorders, allergies, and psychological disorders known as sick building syndrome (Araki et al. 2018) because occupants tend to stay longer in flats than in buildings with other functions such as offices or schools. Therefore, there is a need for a design to protect residential areas from exposure to outside dust.

The spread of dust is closely related to wind or airflow which serves as the dust carrier. This is observed from the effect of plane indicators such as type and surface temperature on the concentration of dust spread (Liu et al. 2020). Therefore, some other theories related to the influence of flat design, dust, and plane on dust control and spread are also explored in this study. Plane geometric shapes are also expected to serve as guides, filters, and dust traps while paying attention to the opening area designed to allow air into the building.

This problem is usually associated with cities located in an industrial area which is usually characterized by PM10 category of dust and 10µm



size. This size normally creates architectural problems by sticking to the aesthetics of the building and reducing the natural air, thereby, causing discomfort due to the need to close all the openings to avoid the dust. Therefore, the purpose of this research is to examine the design and propose the methods to ensure dust does not stick to the plane easily, take advantage of the wind direction to clean the dust on the surface and determine the position of the openings to be used for ventilation.

Regarding the theoretical aspect of the study focusing on dust and its control in buildings, it will be proposed the building form that can control the dust. Furthermore, the study concepts are expected to provide a better understanding of the control of dust in building design.

Dust is a small particle with a size of 1 to 400 microns originating from manufacturing processes, industries, constructions, agricultural activities, and others conveyed by the wind (Department of Health and Human Services, Centers for Disease Control and Prevention, and National Institute for Occupational Safety and Health 2013). Furthermore, dust is also used as an indicator of pollution severity in an area (Rendra, Pudjiastuti, and Sentosa 1998). This is due to its ability to cause allergies, concentration problems, and respiratory disorders (Laumbach 2008). It can also interfere with the aesthetics of buildings by damaging materials, closing the pores of plants which further affects the photosynthesis process, and changing the climate at the regional and international levels (Rendra, Pudjiastuti, and Sentosa 1998; An et al. 2018).

There are three types of dust and these include 1-10 μm and 10 μm sizes as well as those originating from the total particulate matter in the air (Department of Health and Human Services, Centers for Disease Control and Prevention, and National Institute for Occupational Safety and Health 2013). The spread of dust is influenced by airflow or wind (Aristodemou et al. 2018). This means the wind is an important concept in determining the appropriate building plane shape. In principle, a higher wind speed is expected to carry more dust (Mukai, Siegel, and Novoselac 2009). According to Beaufort, an inventor of the wind speed scale, believed dust can be carried by winds at a minimum speed of 5.5 m/s (Chen et al. 2007).

Dust control in buildings

Previous studies showed that dust spread can be basically controlled by using a prevention principle, creating a dust collection system, and isolating the occupants from exposure through a closed room system with fresh and clean air (Department of Health and Human Services, Centers for Disease Control and Prevention, and National Institute for Occupational Safety and Health 2013). Some of the applications commonly used for dust prevention in buildings (Joshi 2008) include:

1. A mechanical ventilation system with a fan, a vacuum cleaner, and a ducting system but requires a large amount of energy (Thomas 2006).
2. The use of plants that can grow anywhere and are resistant to extreme exposure to weather and pollution as dust control (Sett 2017).
3. Regulations by the building management to limit cigarette smoke
4. Placement of residential buildings away from pollution sources such as industrial areas or roads.
5. The design of the building layout to ensure private areas are not directly exposed to wind sources. For example, a room with an open layout can easily accept dust compared to those with a lot of partitions.

From the literature studies, it's known several tower building types such as tower I, tower U, tower H, etc. herewith the analysis studies that focus on the control of dust in flat buildings such as:

1. Tower I building

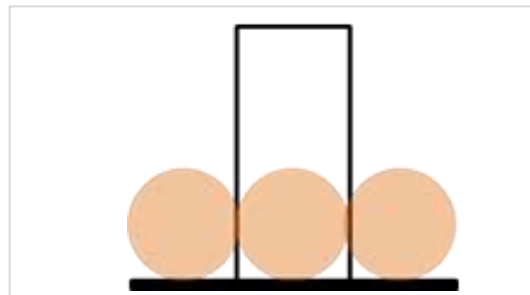


Figure 1. Dust analysis on tower I building

Figure 1 shows that dust can be easily carried by the wind and also experiences difficulty sticking to the surface. Meanwhile, an increase in the speed of wind flow to the plane surface usually causes discomfort to the building occupants. In

case of turbulence, dust can stick to the back of a building (Simiu 2011; Aristodemou et al. 2018; Crummer 2019). Therefore, a perpendicular plane is proposed to be positioned perpendicular to the direction of the wind in this research in order to ensure the dust is concentrated on the downside. However, a strong wind is expected to remove the dust and make sure those on the back side cannot easily stick to the inclined plane composition.

2. Tower I building with different heights

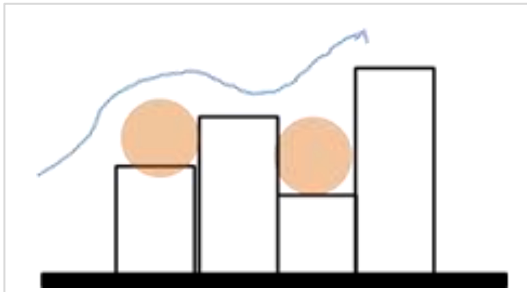


Figure 2. Dust analysis on tower I building with different heights

Figure 2 shows that the height of the building changes the wind direction due to turbulence. For example, the side area which is usually clean suddenly becomes dirty due to the change in the wind flow direction (Simiu 2011; Aristodemou et al. 2018; Liu et al. 2020). Therefore, the height of the building mass is made the same in this research to ensure more control of the dust spread.

3. A curved tower building

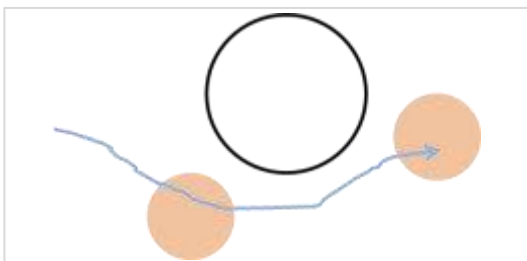


Figure 3. Dust analysis on curved tower building

Figure 3 shows that dust can be easily carried by the wind and find it difficult to stick to the surface. However, an increase in the wind flow speed on the surface of the plane can cause discomfort to the building occupants (Simiu 2011; Aristodemou et al. 2018; Crummer 2019). The curved shape is not selected in this research to facilitate the control of dust spread.

4. A tower podium building

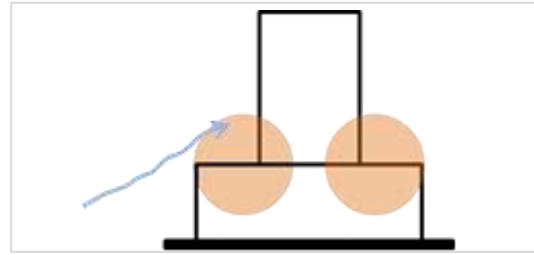


Figure 4. Dust analysis in building with tower podium

Figure 4 shows that the dust is concentrated on the upper side of the podium floor due to the downwash effect and the direction of the wind flow which tends to be on the roof side of the podium (Simiu 2011). This podium shape is, however, not selected in this research because it allows easy collection of dust on the podium roof area.

5. A pyramid tower building

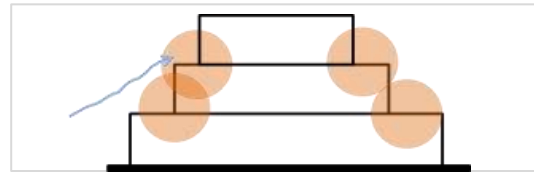


Figure 5. Dust analysis of the pyramid tower building

Figure 5 shows that dust is concentrated on each floor of the pyramid due to the reduction of flow speed which makes it difficult to remove the dust easily (Simiu 2011). This pyramidal shape is, therefore, not included in this research because it collects dust easily.

6. A building with a narrow mass composition structure

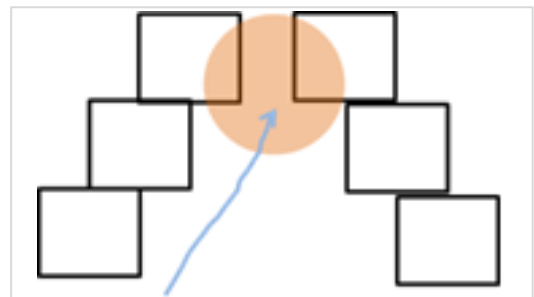


Figure 6. Dust analysis in a narrow composition structure

Figure 6 shows that the dust spread is very fast due to the venturi effect (Simiu 2011). This led to the avoidance of the gaps causing the venturi effect in this research.

7. A courtyard building

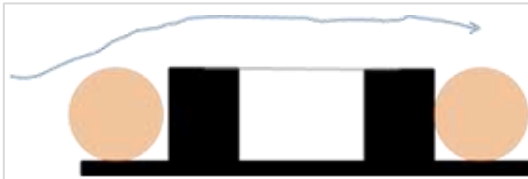


Figure 7. Dust analysis of courtyard building

Figure 7 shows that dust tends to be trapped on the outside and finds it difficult to enter the building because the wind tends to move on the upper side (Simiu 2011). Therefore, the courtyard shape was included in order to control the dust spread.

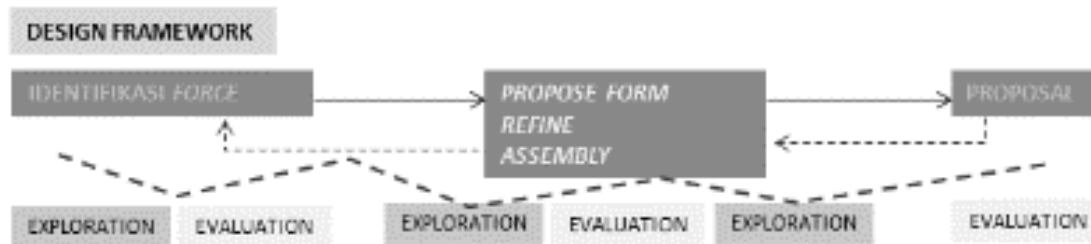


Figure 8. Process and method

Source: Adapted from Plowright (2014) and Jormakka (2007)

Result and discussion

The proposed form-refine in this design is the shape exploration stage where the concepts used to determine the geometric design were explored. This was followed by the assembly stage as the design transformation and the proposal as the final result.

Force identification

The force identification stage is focused on searching for the context-culture-needs. The site was observed to be located right on the Tentara Pelajar road in Cilacap City, Central Java as shown in figure 9. It is an industrial area with a medium-high concentration of PM10 dust. The area is easily accessible due to the transportation and infrastructure for gas, electricity, and water. It

Method

This research was conducted to examine the design of the building using a force-based framework consisting of three stages which are 1) force identification, 2) proposed form-refine-assembly, and 3) proposal (Plowright 2014) as indicated in figure 8. The geometric shapes were determined in stage 2 (propose form-refine) using several methods such as simulation which was later evaluated at the assembly stage to produce the proposal.

Besides, the composition of the mass was based on the wind direction, solar requirements, view, and plane slope besides considering building shape ability for controlling dust. The search process also was assisted by simulation software, Autodesk Flow Design, to determine the wind speed, airflow, and pressure on the surface (Baghaei Daemei et al. 2019).

is also projected to become a new district in the process of developing the city.



Figure 9. Site location

The culture that is influencing in flat developments is about density of the area. In this

research, the site is that it is on the edge of the highway near commercial and residential areas and not too crowded, thereby, indicating easy access for wind. The buildings are also averagely 1-2 floors without any barrier to dispel dust from entering the site.



Figure 10. The surrounding area of the study site

The needs of the flats design are like dwellings unit and public facilities. Nevertheless, in this design the existing needs include the shape of the building to be used in minimizing. This is required in dust control theory to identify the typical buildings to be selected in this design. Therefore, the courtyard shape was selected due to its ability to reduce the dust entering inside.

Proposed form – refine as the concept exploration

The geometric plane to be developed is expected to be positioned in such a way that the wind flow can have the ability to remove the dust on the surface. This is necessary because it has been previously reported that dust easily sticks to concave surfaces (Yu et al. 2017) which are unavoidable shapes in apartment design. Moreover, these curve surfaces also create a circular tower effect which causes turbulence and discomfort to the building occupants and makes it difficult to control the dust spread (Crummer 2019). Trial and error were conducted at this stage to determine the appropriate mass composition based on the direction of the wind flow from the outside, sunlight, and the view of the building to the surrounding environment as well as the shape configuration of the plane slope.

The wind at the site was observed to be flowing from the West-South side at 5.5 m/s. Moreover, the surrounding area is not too dense, thereby, allowing easy and direct movement of the wind into the building as shown in figure 11.

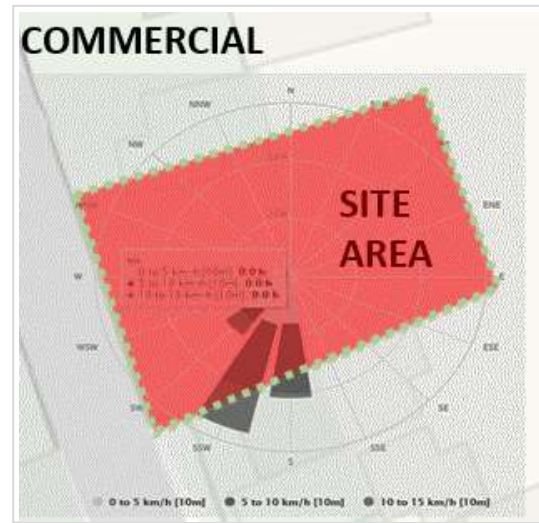

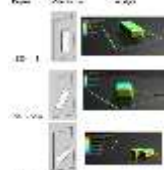
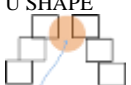


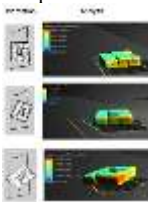


Figure 11. Wind direction on the site based on Windrose

The next stage was to analyze the shapes of the available buildings based on the direction of wind flow such as linear with 1 building, I shape with two building masses, U shape, and courtyard shape as shown in table 1. The analysis showed that the courtyard shape has the most optimum control over the direction of wind flow from the outside. This is due to the fact that the exposure to strong winds is on the outside while there are openings inside to supply the natural air needed in the residential buildings as stated by Maharani, Ekasiwi, and Samodra (2019) as well as in accordance with dust control theory previously stated.

Table 1. Various economic activities in the Semarang Chinatown area

Theory	Trial and error	Conclusion
<p>I SHAPE</p>  <p>The presence of turbulence on the surface of the plane leads to the concentration of dust on the bottom side</p>	 <p>The direction of the wind flow causes turbulence on one side which causes the dust to be concentrated on a certain side.</p>	<p>I Plane will make the dust concentrate on a certain side.</p>

Theory	Trial and error	Conclusion	Theory	Trial and error	Conclusion
<p>U SHAPE</p>  <p>The dust spreads very fast due to the venturi effect.</p>		<p>Shapes that have a gap such as a letter U should be avoided to stop dust from settling easily on the surface of the gap.</p>	<p>COURTYARD</p>  <p>Dust tends to be on the outside and find it difficult to enter the building.</p>		<p>The courtyard shape can be selected because the dust is on the outside while natural ventilation can be provided by</p>

The building was also analyzed based on the direction of wind flow, view, and sunlight. This involved rotating the building to have an interesting view and the results showed that an orientation slope of 225o to North-South is the most optimal angle to have the best view and wind direction. However, there is a need for additional shading on the west and east sides to reduce the sunlight as shown in figure 12.

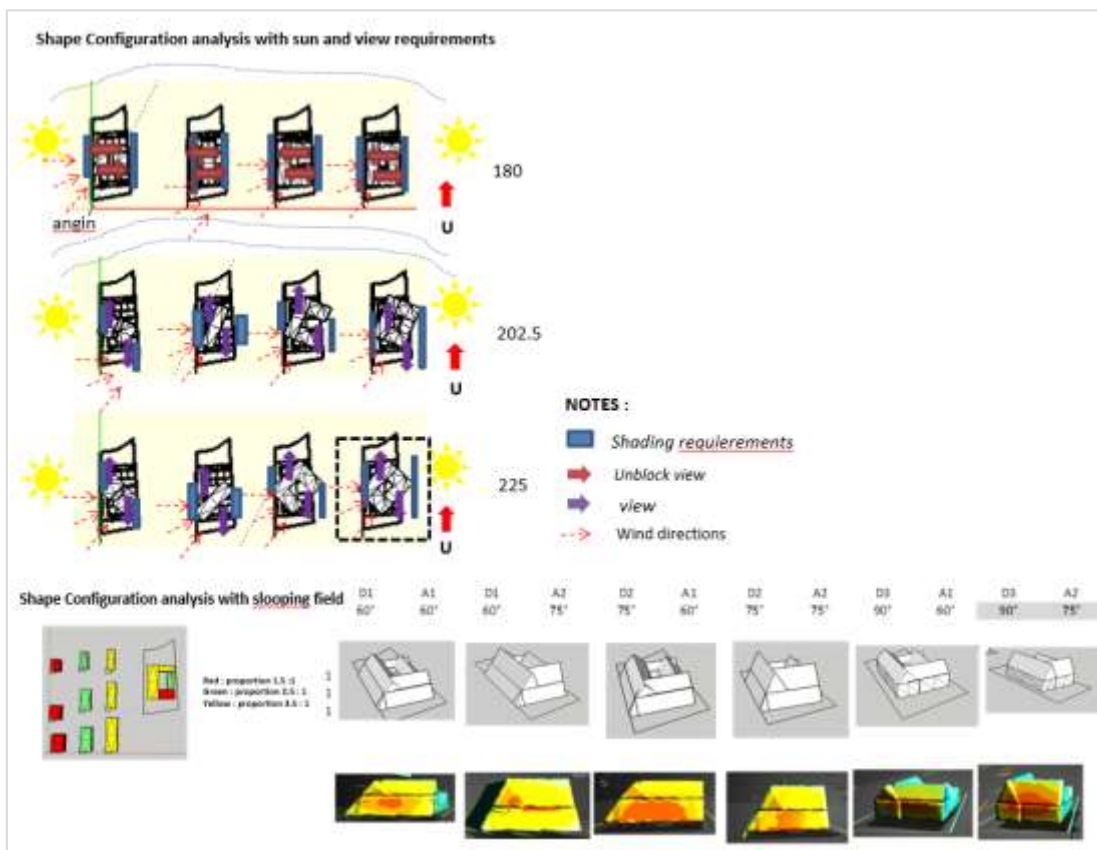


Figure 12. Building shape transformation analysis

The last stage is to analyze the shape configuration to airflow direction on the plane using 60°, 75°, and 90° slope angles selected

because dust sticks more easily at 0o and 30° than at other angles (Qasem et al. 2014). The results showed that 75° and 90° are the most effective

angles due to the fact that the area exposed to the wind is wider and the dust is more likely to be removed. This sloping shape is to be later recomposed to make it really difficult for the dust to stick. Moreover, the wind speed on the surface was estimated to be 5.5-7.9 m/s and this means the dust can descend by itself (Chen et al. 2007).



Figure 13. Building facade concept sketch

The building façade used as the main defense against the dust-carrying winds was also designed in such a way to ensure the dust falls easily (R T Maharani, Ekasiwi, and Samodra 2021). It is important to note that sunlight and air are important in residential houses. This means sunlight which is related to the amount of overhang, view, and exchange needs to be considered by paying attention to the Window to Wall Ratio (WWR) and plane slope. Meanwhile, the overhang does not only provide shadows as stated by Ossen, Hamdan Ahmad, and Madros (2005) but also used as a cover wall with vertical and zigzag patterns as indicated in figure 13.

The building landscape layout is also capable of controlling dust spread. This means the distance between building walls, fences, plants can be adjusted to reduce dust (Sett 2017). A narrow distance usually allows wind to lose momentum to return to its true direction, thereby, creating enough time for the dust to stick (Mediastika and Scanlon 2001). This research used both large and narrow distances to ensure the dust does not always rise to the top of the building but settles in the landscape area to be filtered by the plants.

The building space layout also needs to be considered in determining the location of private rooms or residential units in the areas protected from direct dust exposure. It was discovered that the unit area was designed to be placed on the top floor while the 1st-floor is used as an open and public space to reduce exposure to dust from the

side of the road. Moreover, the service and parking areas are located in the basement to reduce the exposure of the buildings to dust because service area have a possibility to adding the more pollution in this site. The allowable opening or WWR to reduce dust in the wall area is 15% (Pacheco-Torres et al. 2015) but this is not sufficient to fulfill the needs for natural ventilation. Therefore, it is necessary to have additional openings in the atrium courtyard as well as ventilation shaft to optimize airflow (Thomas 2006) as shown in figure 14.

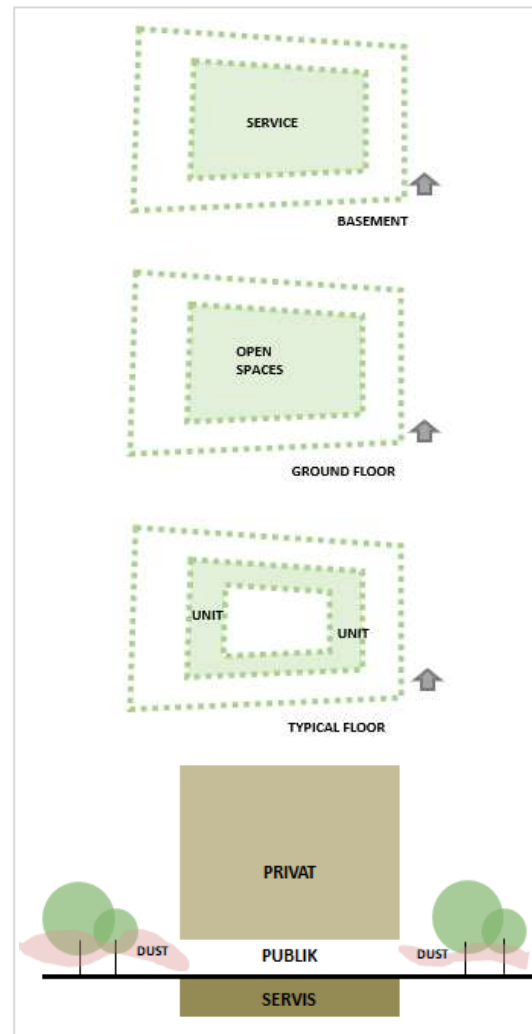


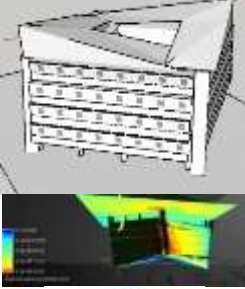

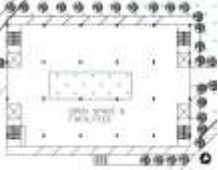
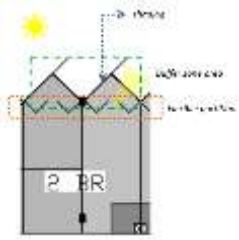

Figure 14. Vertical building zoning concept

Assembly as a design concept

The assembly stage was aimed at the overall design concept process which was evaluated to determine its suitability as a control for dust

spread in the building. The findings are stated in the following table 2.

Table 2. Evaluation of design results

Alternative	Evaluation
	<p>In the composition of the shape on the side, the highest wind was found on the southwest side at 6.3 m/s and this can remove dust on the surface (Chen et al. 2007). Meanwhile, dust is easily trapped on the horizontal side (Qasem et al. 2014), thereby, requiring additional filters.</p>
	
	<p>The 1st-floor area is left open and dust does not enter the residential area due to the vertical distance. In this open area, some planes function as filters on the side of the building.</p>
	<p>The presence of a buffer zone before entering the residential unit in the balcony area is a control effort to reduce dust. Meanwhile, the existence of a flexible partition which serves as a barrier to the entry of dust from the outside into the room causes the room not to have optimal lighting.</p>
	<p>To fulfill the need for clean air quality, it is necessary to have a courtyard area and raise the building floor to allow the entrance of air, similar with stilt house. This is due to the ability of the courtyard shape to allow wind in the upper area of the building (Simiu 2011)</p>

Proposal

The proposal stage is the final result of the form-refine-assembly process in the design transformation stage. It was discovered that the

west area has a barrier wall which has straight planes without indentations and designed to limit the exposure of the building to dust and sunlight as shown in figure 15. Meanwhile, the other side has a gap in the form of an inclined plane at 75° which was used to reduce dust and ensure it is not easily trapped as indicated in figure 16 and 17. The courtyard building shape also has the ability to control wind and dust spread as shown in figure 18. Moreover, the game of gaps between the planes is also designed to serve as a means of protection using hidden side openings to reduce dust intensity. This method has been previously applied in most traditional Middle-Eastern houses (Alkhalidi 2013) but the implementation is different in this research because Indonesia and the Middle East have different climates.

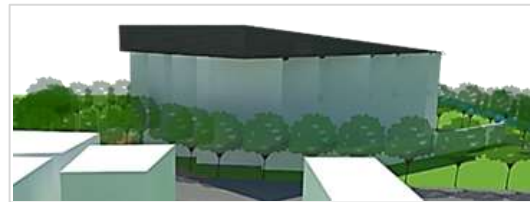


Figure 15. Front view of the building (West side)



Figure 16. Building perspective (Northwest side)

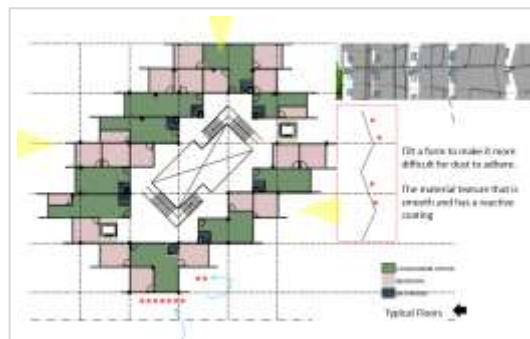


Figure 17. Opening gaps between barrier walls

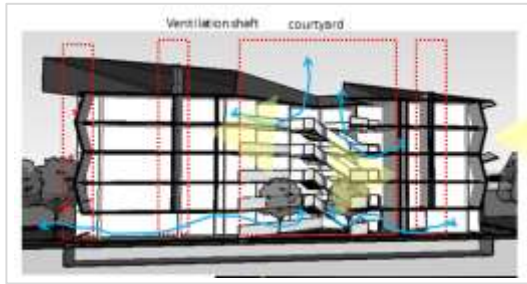


Figure 18. Courtyard area on the building pieces

Conclusion

The site used in this research was observed at the force identification stage to have a high dust intensity and this means there is a need for treatment in designing residential flats in the area. Therefore, the proposed form-refine-assembly stage showed that, first, the geometric shape of the building should be a courtyard pattern due to its ability to hold dust on the outside. Second, 75° and 90° angle geometric planes can be used to hold dust and make its removal by wind or water easy. Third, the presence of an overhang on the facade does not only serves as a shadow but also as a cover or barrier against the dust from outside. Fourth, the use of different plan distances in the landscape can be used to retain the dust. Fifth, additional opening areas are required in the courthouse to fulfill the need for natural ventilation because the WWR allowed to the outside is very minimal. Meanwhile, the proposal stage indicated that a barrier is needed on the side where the dust comes to prevent it from entering the building directly. On the other side, an inclined plane with an angle of 75° can be used to ensure the removal of dust and placement of openings.

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Author(s) contribution

Rizka Tiara Maharani contributed to the research concepts, literature review, methodologies, data analysis, result, article drafting and revisions.

Sri Nastiti Nugrahaini Ekasiwi and **FX Teddy Badai Samodra** contributed to supervision for research concepts, literature review, methodologies, data analysis, result, and validation.

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