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Urban Phytoarchitecture Design Options: Greenspace Orientation and Tree Species Intensification

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ABSTRACT

This paper discussed a new perspective on the path of sunlight as a basis for urban phytoarchitecture design, which empowers the ability of plants to absorb carbon dioxide and simultaneously lowers the surface temperature. The aim was to provide options for intensifying greenspace orientation and plant types as one of the goals of a sustainable city. This research analysed previous research sources collected from the reference management platform. The literature selection uses the keywords greenspace, orientation, carbon dioxide, and surface warming, all of which are the latest publications. The result for the first option was the orientation of the greenspace following the path of sunlight. For urban infrastructure in a North-South direction, it was advisable to intensify greenspace by planting trees that absorb large amounts of carbon dioxide. In addition, it was recommended to apply biodiversity to enhance the absorption of the gas. For East-West oriented infrastructure sites, intensifying greenspace with sunshade trees was the right choice, and biodiversity was not a limiting factor because it does not support leaf area growth. While the first option cannot be followed due to existing field conditions, the second option is intensifying tree species with biodiversity, which can absorb carbon dioxide and reduce surface warming.

1. Introduction

Urban infrastructure is increasingly growing vertically and horizontally to meet population growth, especially residents, and the development of their activities. This condition is a general effect of the tendency of urbanisation in countries on any continent, and urbanisation will continue to increase by more than 50 % of the world's population [1]. Eighty per cent of the world's urban population estimated in 2025 will live in urban centres of developing countries [2]. Along with

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urbanisation and infrastructure development, accompanied by urban areas' expansion, is the pressure on greenspace availability [3,4]. Li *et al.,* [5] developed an urban ecological infrastructure framework to complete the comprehensive urban infrastructure, not only grey infrastructure but blue and green infrastructure. It will work for adaptable and resilient cities.

Environmental conditions become a problem when the area's expansion rate and population activity development exceed the rate of providing greenspace as it is known that the development of population activities also increases the amount of carbon dioxide, both from the respiration of the population and the oxidation of materials used for human activities. Each person emits about 3-5 kg CO_2/d [6]. This amount can contribute significantly to warming the atmosphere and irreversible climate change [7]. Thus, it must be absorbed by environmental media: air, soil, water, and plants. For urban and densely populated cities, the absorption of carbon dioxide by land and water may be insignificant [8]; hence it is practically dependent on air and plants. Air does not use carbon dioxide, but plants need it for sustainable life. Microclimate measurement indicators will be significantly effective if the total site factor adjusts the site configuration, sky view factor, and green plot ratio [9]. The Intensification of greenspace has become urgent and very important in responding to actual problems today. Everyone in the world is living during the COVID-19 pandemic. Therefore, everyone needs new habits in responding to this era and the next. Essential new practices include wearing masks, keeping distance between people, and using antiseptics and disinfectants in water use. These produce more wastewater enriched with toxic substances [10]. One way to control toxicants is by greening the environment, particularly trees' dendroremediation of polluted soil [11,12]. The potential solution to a greening environment is the implementation of greenspace intensification for natural resources efficiency. This paper focuses on the air quality parameters, carbon dioxide, and the spatial distribution of greenspace, which was introduced as phytoarchitecture [13]. This gas is an essential requirement in photosynthesis, but its abundance has a surface-warming effect.

Therefore, this paper aims to provide options for suppressing carbon dioxide and surface temperature through a novel approach for greenspace intensification based on sunlight pathways and plant species. The authors deliberately took Jodipan Village at Malang City, Indonesia, as the locus to demonstrate the real field conditions. This village had a new branding after recolouring and became a city tourism destination. Meanwhile, the location lacks greenspace because the areas are covered by dense residential.

2. Methodology

This study was on the scale of urban areas, which defines phytoarchitecture as providing space for plants to empower them as natural processors and managers of the environment [13]. Phytoarchitectural design focuses on structuring the distribution of greenspace places in an urban area, for example, along bodies of water, roads, undulating land, parks, and other infrastructure spaces [14-16].

Literature exploration through Mendeley's reference manager uses keywords related to greenspace and vegetation, which can reduce carbon dioxide and surface warming. Environmental factors to be considered include heating on surfaces and their effects on living organisms [17-21]. The most recent available articles are visited at published sources, their main ideas are studied through abstracts, and then they are selected as sources for analysis. However, the existence of literature on greenspace orientation based on sunlight's trajectory still needs to be improved. Therefore, this review used research results on planting food crops. There was no significant difference between various food plants and different types of plants for greenspace to the need for sunlight for photosynthesis in connection with plants' absorption of carbon dioxide.

Several examples were provided for subtropical and tropical regions regarding tree species' choice for two functions: absorption of gases and cooling. The architectural designer was advised to consult with agricultural and forestry institutions and the community to choose the appropriate tree species on site. In the end, a selected area for greenspace assessment based on phytoarchitecture was provided.

3. Results and Discussion

Various empirical studies on north-south-oriented planting show that plants are the main component of the global carbon cycle. Net primary productivity and carbon storage for hundreds of subtropical and tropical tree species exhibit steadily increasing mass growth rates. These results explain the same treatment of sunlight for each plant to absorb carbon in the process of photosynthesis. While planting in the east-west direction shows a dominant effect on the weakening of land surface temperatures. Planting in the direction of the sun's trajectory makes the plant a protector of the land surface from the sun's rays.

3.1 North-South Orientation

The sun rises in the east and sets in the west with exposure to various light spectra. Among the light spectra is photosynthetically active radiation [22]. Photosynthetic active radiation (PAR) is the spectral range of solar radiation from 400 to 700 manometers used by plants in photosynthesis [23]. It is the basis of any plant growth and development analysis, in which PAR transforms carbon dioxide into plant biomass. This basis is essential to become one of the bases for greenspace orientation planning.

Absorption of this PAR is best obtained in rows of grapes oriented in the North-South, Northeast-Southwest, and Northeast–Southwest orientations [24]. The researchers' analysis included a North-South, Northeast-Southwest, Northwest-Southeast, and East-West orientation and varied over geographic latitude, from 30 to 50°N, to represent the various latitudes in which grapes grow around the world. The researchers collected field data and calculated predictions by modelling. The field data results show the advantage of a North-South and Northeast-Southwest line orientation to maximise PAR uptake. However, exploratory analysis by model simulation shows that PAR uptake is lower for the East-West line direction. They concluded that in arid and semi-arid environments, grape cultivation with a North-South orientation and Northeast-Southwest row directions was advantageous over other orientations.

Similar research has been carried out by Chorti *et al.,* [25]. The orientation of the vineyard rows played an essential role in determining the yield of the grapes, so the researchers conducted the study on a flat site with a two-row orientation, North-South, and East-West. Growth parameters and yields were examined, and it was found that grape colour was preferable to East-West oriented plantings. However, for wine quality results, the researchers stated that grapes at North-South orientation showed generally superior.

Recent studies of this type show that vineyards under the North-South orientation increase the vine's strength and promote better phenolic maturity in grapes harvested during winter than in the East-West orientation [26]. The researchers started from the premise that the orientation of the grape rows, which were in line with the sun's trajectories, had an important influence on the yield of the grapes. Therefore, the research was carried out utilising vertical planting in these orientations. The researchers found that the vegetative vigour was increased in North-South oriented vines. They considered it due to high photosynthesis, as indicated by the highest leaf starch accumulation.

Likewise, the fact is that the North-South orientation increases the cluster weight. Therefore, the researchers concluded that vineyards with a North-South orientation increased the vine's vigour and promoted better phenolic maturity in the grapes harvested than in the East-West orientation.

Interesting to study the results of research related to the orientation of hedgerows. The following is a summary of the work of Trentacoste *et al.,* [27], who examined the productivity of olive plants. The facts obtained that the North-South-oriented hedgerows produce 20% more products than the East-West orientation. However, it is also known that the East-West orientation can manipulate the canopy microclimate, both temperature and water availability. It is further known in depth that the orientation of the North-South fence between plants spaced 2-5 m apart can produce a significant increase in olive oil by up to 50% over five years. Based on these facts, the quality of olive oil is examined. Analysis of the relationship between radiation related to hedgerows' orientation and soil quality can help improve the design and management of olive hedgerows intended for oil production. Furthermore, Moreno-Alías *et al.,* [28] confirmed the nature of olive trees that are very responsive to sunlight radiation, determining the quality of flowers. One of the determinants for obtaining sunlight radiation is the orientation of the hedgerows.

Learning from research results in different places and different types of plants show that North-South oriented greenspace is therefore promoted. It is because each plant receives the same daily radiation under sunny and cloudy conditions. Furthermore, the stoichiometric process of photosynthesis concludes that with the acquisition of solar radiation at each position of the North-South pathway, each plant's position absorbs carbon dioxide and produces higher biomass than the East-West orientation.

Several trees that are known to be able to absorb large amounts of carbon dioxide and other gasses are shown in Table 1. Selection of tree species with consideration of two factors. The first factor is the growth parameter, which indicates the ability to absorb much gas as the appearance of fast growth.

Table 1
Some trees absorb large amounts of gases

Local/common name	Scientific name	Existence
Honey locust	*Gleditsia triacanthos* [29]	Subtropical area
Callery pear	*Pyrus calleryana* [29]	
London plane	*Platanus ×hispanica* [29]	
Rain Tree	*Samanea saman* [30]	Tropical area
Yellow-flamboyant	*Peltophorum pterocarpum* [30]	
Acacias	*Acacia mangium* [31]	

The growth parameter refers to the stoichiometry of the photosynthetic process. This type of tree that absorbs a lot of carbon dioxide gas results in growing biomass quickly. It visually is the emergence of many new shoots growing, and fast trees are tall, the diameter of the stem increases rapidly. Of course, the environmental conditions do not harm their growth, for example, polluted soil and air. Researching a greenhouse on various types of trees in environmental conditions without and with pollution simulations is necessary. Here, the authors do not further explore tree growth in polluted environmental conditions, as this is the specificity of the bioindicator study [32]. Confirmation of the relationship between the amount of carbon dioxide absorption and tree growth was carried out by Stephenson *et al.,* [33]. Instead, they have studied plants as a significant component of the global carbon cycle. Especially the relation of air greenhouse gas concentrations changes in the forest carbon cycle. In-depth research has focused on net primary productivity and carbon storage for hundreds of subtropical and tropical tree species. Their results show that for most species, the mass growth rate is steadily increasing, which acts as a carbon sink and actively binds large amounts of carbon.

The second factor regarding the amount of carbon uptake is biodiversity. Gamfeldt *et al.,* [34] reported that tree species richness in an ecosystem increases tree biomass production and soil carbon storage. The researchers gave examples of the production of several berries, the biomass of about 50% greater than that of a single tree species. Next are Castro-Izaguirre *et al.,* [35], who confirmed the relationship between biodiversity and biomass productivity and focused on herbaceous ecosystems. Their research found that species-rich forests support a positive productivity-diversity relationship. The recommendation is to encourage tree diversity to accelerate the absorption of carbon dioxide from the atmosphere. Multi-species schemes in an area are more advantageous than single species because there is an effect of increasing carbon sequestration [36]. Researchers have worked on forest ecosystems as an integral component of the global carbon cycle. Trees undertake the transfer to absorb and release carbon quickly but accumulate it much longer than the transfer process. Researchers have studied variations in dozens of tree species and tree ages annually. The results showed that a multi-species tree cluster had a higher carbon fixation rate than a single-species cluster [37].

Greenspace is applied for road lanes, water bodies, settlements, and other infrastructure buildings. These are mainly places that produce a large amount of carbon dioxide release. Some are transportation, commercial and industrial activities [38,39].

3.2 East-west Orientation

A lack of research related to greenspace based on sunlight trajectories directed this review uses the shade research results approach to cooling the earth's surface temperature. The benefit of vegetation in urban areas is that the trees act as a mask for the sun and wind and as a source of control of the ambient air temperature and surface temperature. This greenspace's effectiveness depends on its plant density, shape, size, and orientation [40]. It is also confirmed by Wang *et al.,* [41] that the cooling capacity of urban trees to respond to extreme temperatures is dominated by plant transpiration.

Referring to the study of Trentacoste *et al.,* [42], the East-West orientation can also be known to manipulate the microclimate of a plant's canopy. Earth's surface temperature is lower than others, and more water is available because evaporation is declining compared to the North-South orientation. Additionally, a study evaluated the effect of growing coffee in an East-West orientation on microclimate aspects, plant growth, and nutrient content. Leaf temperature, plant growth, and leaf concentration on both sides of the plant were evaluated. There was no significant difference between the two sides of the plant for growth variables. Radiation deficit values, air temperature, and vapour pressure were obtained around 4°C to 11°C at noon [43]. These results indicate that greenspace's orientation with an East-West orientation significantly cools the earth's surface temperature and provides environmental comfort in green areas.

The thermal comfort assessment for pedestrians was undertaken because people outside could be more susceptible to heat stress and heatstroke. The road sidewalks microclimate is modified using tree canopy cover [44]. With variations in the modification of the distance between trees and the road's orientation, the reduction in air temperature under the canopy cover is more significant than 1.2°C for East-West roads than North-South roads [45]. Similarly, in the results of research on the orientation of a building's green landscape, Ojaghlou and Khakzand [46] recommend the East-West pattern as the optimal pattern for designing gardens that are more comfortable than other orientations. It was also confirmed by the analysis of the orientation and vegetation elements in increasing thermal comfort [47,48].

Heat mitigation strategies have been investigated for urban yards [49-51]. It considers spatial configuration; of course, the East-West direction experiences solar radiation longer than the North-South direction. The result of ponds of water and urban vegetation is to cool the microclimate significantly [52]. In other words, greenspace in the East-West orientation is the choice to cool the environment.

3.3 Tree Species Diversity

Tall tree species and broad leafy canopies are suitable for application as East-West oriented greenery. Several trees that are known to provide shade and reduce heat are shown in Table 2.

Edelkraut and Güsewell [53] have examined changes in the composition of plant communities in response to changes in light intensity through artificial shading variations. At the start of the study, nine species were in the plant community. It was found that shade did not affect biomass growth in the community. However, in the long term yearly, shading affects reducing biomass and does not affect decreasing biodiversity. These results suggest that the reduction in biomass can be in all parts of the plant, including leaf growth. Leaves are relied on as shading so biodiversity does not support shading for the environment.

Table 2
Some trees function to shade and reduce heat

Local/common name	Scientific name	Shading effect (canopy radius, m) [54]	Thermal reduction (°C) [55]	Existence
Common hackberry	*Celtis occidentalis*	6.55		Subtropical area
Small-leaved lime	*Tilia cordata*	3.65		
Japanese pagoda	*Sophora japonica*	2.85		
Merawan	*Hopea odorata*		9.2	Tropical area
Cajuput	*Melaleuca cajuputi*		8.8	
Yellow-flamboyant	*Peltophorum pterocarpum*		5.1	

De Abreu-Harbich *et al.,* [56] conducted experiments on twelve tree species in cooling the environment due to the shading effect. The tree treatments include single species and diverse tree groups, and the temperature size is expressed as equivalent physiological temperature based on human thermal comfort. This experiment obtained the fact that there is a single species that can reduce the temperature up to 16°C. However, the reduction in temperature was only up to 14.5°C for the cluster, multi-plant communities. The results of these studies confirm no support for environmental shading with plant variety applications.

Referring to Castro-Izaguirre *et al.,* [35] found that leaf area was not even negatively affected by tree diversity, indicating the release of accumulated carbon from leaf area. Perhaps the reason is that the leaves of a single species can accumulate carbon over a long period, whereas the leaves of multiple species experience competition between species during this long period. Therefore, the application of biodiversity to shade functions is less meaningful.

Greenspace is applied for road lanes, water bodies, settlements, and other infrastructure buildings. These are mainly the places that require a comfortable and cool microclimate. Some are sidewalks, housing, city parks, and settlements in the mountainous landscape [57]. Steeneveld *et al.,* [58] examined the correlation between urban heat islands with dense populations. The urban heat island worked to scale down when the surface area was covered dominantly by trees. Another research claim is that urban greenspace, and social-health life similar ecosystem services. It determines the community's physical, psychological, and social health [59].

The empirical study of Zaki *et al.,* [60] showed the trees' trajectory existing dominantly in the North. The dominant trees name *Pterocopus indicus*. Meanwhile, there are no trees along with the water bodies at the East-South trajectory. There is why the residential and surrounding had a hot climate, dusty and arid. The previous research showed that this area should have environmental management to reduce air and water pollution, waste, and disaster prevention [61].

In the practice of using tree species, according to the results of research by Aminsyah [62], the types of trees planted were Rain tree (*Samanea saman*), Teak (*Tectona grandis*), Redwood (*Pterocarpus indicus*), Mahogany (*Swietenia mahagoni*), Burflower-tree (*Neolamarckia cadamba*), and Flamboyant (*Delonix regia*). In the parks, the community of planted trees gives a cooling effect of 4-6^{o}C, while outside the park shows a temperature of 32^{o}C. However, the effect of tree species and diversity on temperature reduction is local and varies depending on existing tree cover, geometry and meteorological conditions [63,64].

3.4 Greenspace Intensification in Selected Area

Indonesia has central government regulations as references for cities and regions in issuing local regulations on greenspace. Central government regulations are issued by the Ministry of Home Affairs [65], the Ministry of Public Works [66], and the Ministry of Forestry [67]. These regulations regulate roles in providing greenspace, from the legislature, executive, planners, designers, non-governmental organisations, and the community. In principle, everyone should provide, maintain, monitor, and even safeguard the law.

The Ministry of Home Affairs regulates the basics of greenspace requirements and their planning. The need for greenspace prioritises environmental quality and its effects on its residents. Meanwhile, according to the Ministry of Home Affairs' authority, the planning includes allotment, placement, area, and administrative aspects. As the ministry in charge of technical public works, the Regulation of Ministry of Public Works was issued, a technical guideline for implementing greenspace. Meanwhile, the Ministry of Forestry Regulation focuses on understanding the provision of urban forests and defines their intentions. Qualitatively describes the provision of the urban forest to maintain environmental quality. Quantitatively, an urban forest is defined as a dense stretch of at least 25% of the service area. In the development plan, the types of urban forests must be broken down into various areas: residential, industrial, recreational, germplasm preservation, protection, and security. For each type of urban forest, the function of the forest and the type of tree are specified. For example, urban forest-type residential areas that function as oxygen producers, carbon dioxide absorbers, water absorbers, windbreaks, and noise absorbers, in the form of tall tree compositions combined with shrubs and grasses.

The three central government regulations are complementary. However, concerning greenspace orientation, the existing regulations have not provided direction. Therefore, it is necessary to assess the selected area, where a lack of greenspace makes it prone to environmental problems. The selected location for the empirical study was in Brantas River Bank, at Jodipan Village, Blimbing District, Malang City, Indonesia. Brantas River Bank was known as one big river through Malang City and Jodipan Village, which was one area through this river. Jodipan Village has become a famous tourist destination for its unique colourful branding. However, greenspaces were lacking as an ecosystem service to avoid floods and landslides [68]. Figure 1 depicts one at Jodipan Village that, through by Brantas River (blue line) and landslides potential (red line), also lacks greenspace.

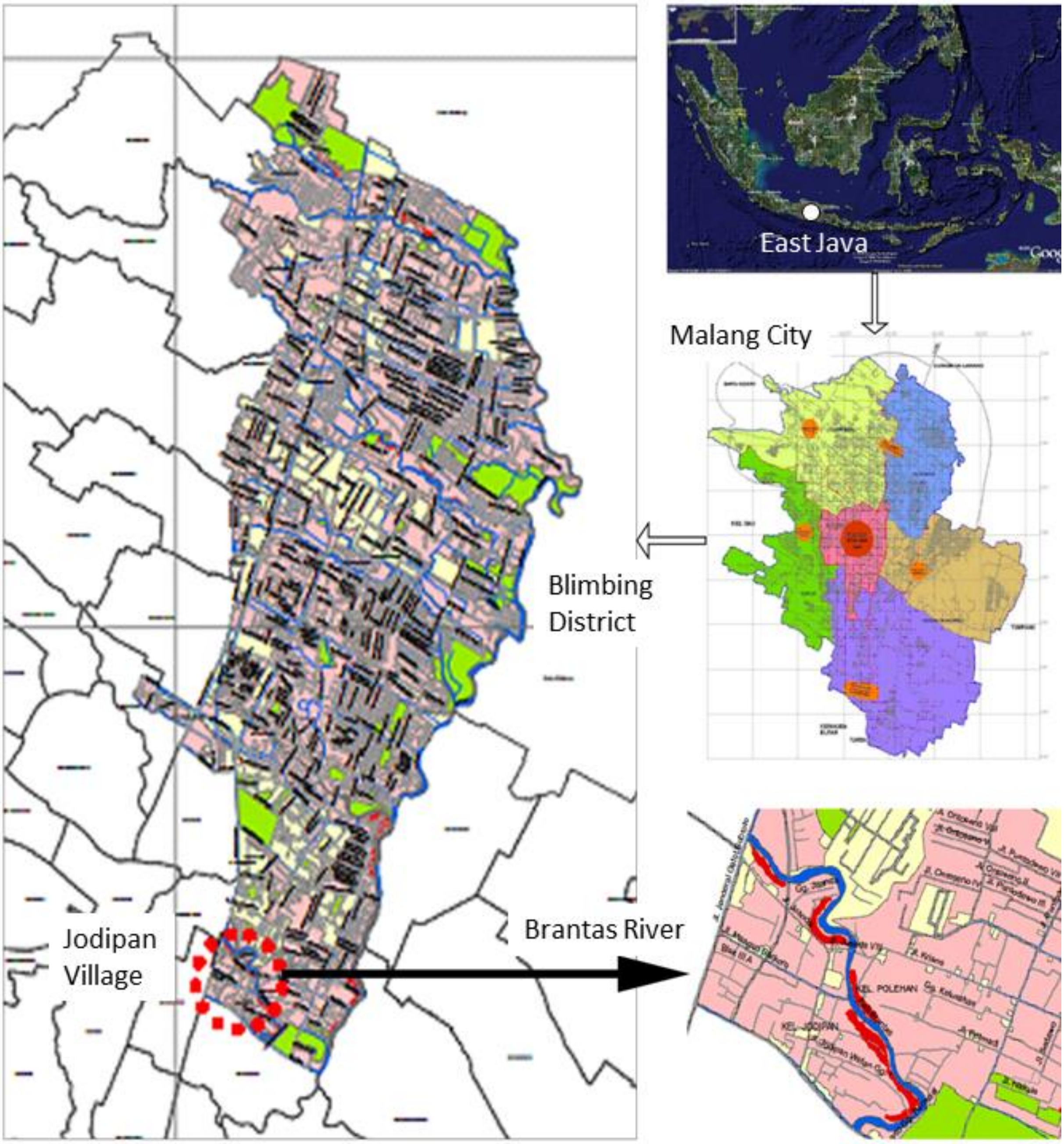

Fig. 1. Map of Blimbing District landslides potential [69]

The direction of greenspace and tree types arrangement for different infrastructure orientations deserves essential attention. Implementing greenspace for a new urban area may be manageable by applying the principles of mitigating carbon dioxide and heat. However, this is not the case for areas that have been developed. Therefore, implementing greenspace based on this orientation choice intensifies the existing greenspace. This difficulty was faced by the first author when planning greenspace intensification and monitoring in that selected area since 2019 (Figure 2). Intensification of greenspace in the orientation of the path of sunlight was difficult, so it was chosen by intensifying local tree species, namely *Pterocarpus indicus*, which can absorb carbon dioxide while cooling the surface through the canopy shade [69].

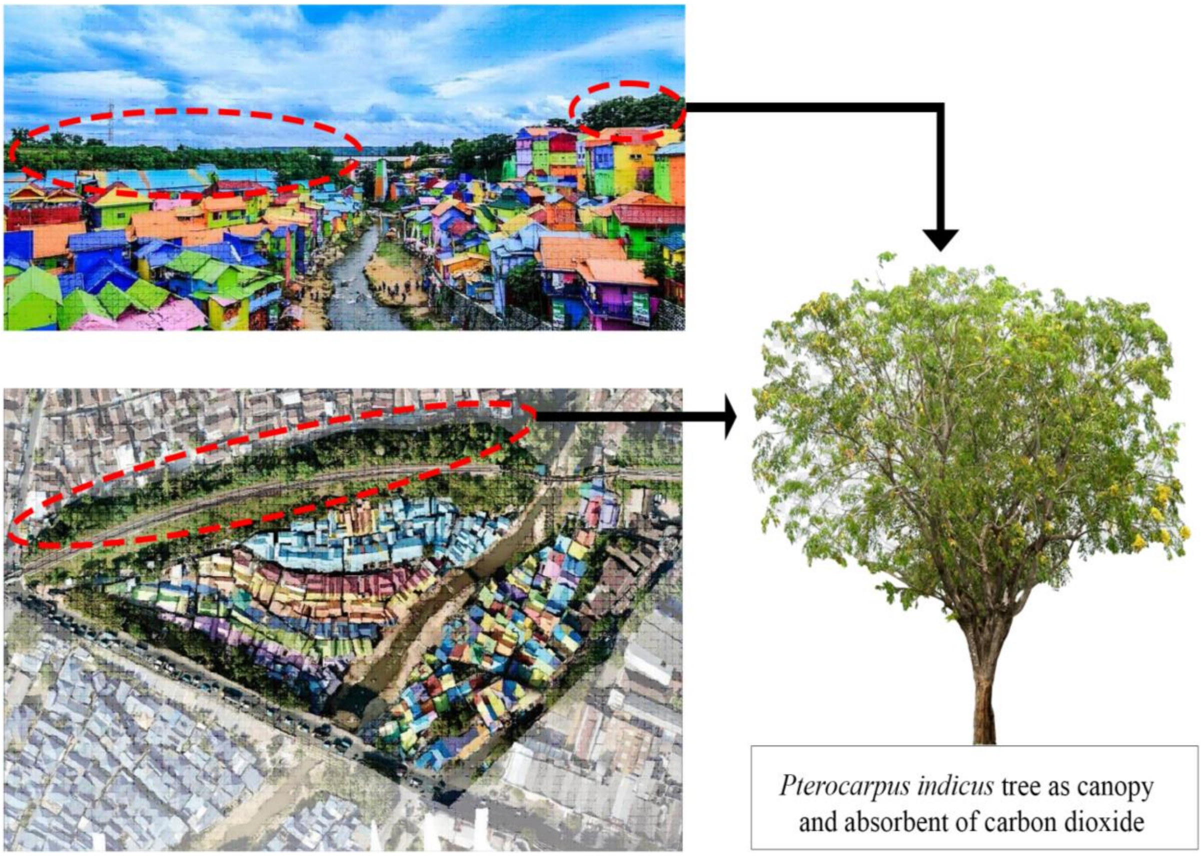

Fig. 2. Greenspace orientation and tree species intensification in Jodipan Village [70]

Buildings and landscape architecture do not ignore trees' presence for aesthetics, especially for an urban environment's convenience [71,72]. Greenspace stores heat and humidifies the atmosphere through evaporation, significantly reducing surface temperature [73,74]. Reducing surface temperature affected the thermal comfort of the outdoor and indoor environment of the buildings [75,76]. Planners must identify issues that are urgent to control, such as carbon dioxide emissions. In this case, the recommended solution was to intensify greenspace on pathways with the maximum potential to absorb carbon dioxide and intensify tree species. In addition, the choice of plants needs to pay attention to local plants and the local wisdom of plants [77-79]. This consideration was related to community acceptance of greenspace intensification, thus supporting a sustainable city.

4. Conclusions

The North-South orientation greenspace was suitable for using plant species that can absorb carbon dioxide. In that orientation, it was recommended to apply biodiversity because it increased the absorption of the gas. In contrast, East-West oriented greenspace was suitable for using plant species that could produce shade to cool the earth's surface temperature. In this orientation, biodiversity was meaningless for shade function, as they competed with each other for carbon dioxide, which did not support the growth of the leaf area. Therefore, urban infrastructure with positions other than these two orientations can choose the Intensification of tree species that can absorb carbon dioxide and reduce surface warming.

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