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Fabrication Engineering And Sustainable Urbanism: The Case Of Vertical Housing Development In Indonesia

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ABSTRACT

Engineering is a principle of science in the implementation of design, construction, and efficient operation of frameworks, equipment, and economic systems, with the aim of assuming that it facilitates the optimal solution of human problems. Sustainable Urbanism is the study of cities and their development methods that campaigns long-term sustainability through the reduction of resource consumption, waste, and adverse impacts on people and the environment, while improving the overall well-being of the population and the city itself. Fabricated in Architecture is an innovative construction method with building elements fabricated in advance at the factory, thereby speeding up processes, reducing errors, and minimizing waste. All three are integrated in the engineering of sustainable residential megastructures, which effectively maintain the "importance of blue skies and green open spaces" that humans feel so strongly about, especially during the rise of natural disasters such as floods, earthquakes, and extreme climate change. This approach combines prefabricated fabrication for engineering efficiency, sustainable urbanism principles for long-term environmental resilience, and smart vertical design to create eco-friendly housing amid an increasing urban population density. The research used the literature review method and was analyzed using the descriptive analysis method.

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1. INTRODUCTION

The phenomenon of urbanizing the world has long been hailed as a solution to the problem of urban settlements (Abrams, 1964). However, due to the human phenomenon that centralizes economic activities in big cities, the process of urbanization was born (Cherry, 1974) (Golany, 1976). Doxiadis in 1971 tried to read settlements by looking at five elements, namely: nature, shells, network, man, and society and classifying them into several scales, namely the scale of settlements, the urban scale to the scale of the network between cities globally (Doxiadis, 1971) Because basically, to know and understand a city, we must know these five elements. Mega-scale housing development in Indonesia acts as a driving force in urban industrialization but also has vulnerability to welfare disparities and environmental quality degradation, so an approach is needed that can make cities sustainable cities. According to Kevin Lynch (1990), To understand the city, we also need to look at five elements, namely: paths, edges, districts, nodes, and landmarks.

Property development with *the concept of Transit Oriented Development* (TOD) is the prima donna (Asfarinal, Barus, & Djaja, 2022) (Nazwar, 2021) in the property sector. Because the concept that integrates housing with public transportation modes is one of the factors that sells well in this contemporary housing concept. Through this concept, people are facilitated by not having to use private vehicles in their activities, most of which are in Jakarta. People only need to come to the nearest terminal or KRL station and are in the same area with housing. Knowing the concept of TOD, the public will find that most of them are developed in the form of superblocks or mixed-use developments that unite various property products in one unit (Trisnawati, 2020). Urban residential development (Prayitno, 2020) It is necessary to integrate the aspects of clean air quality and green open spaces. Urban residential engineering without having to experience "untouchable earth" in its study. Until now, the integration of how the area functions with development with the concept of TOD and *Sustainable Urbanism* is needed as the basis for the emergence of development principles as the next foundation.

2. RESEARCH METHOD

This study uses a systematic literature review approach with descriptive analysis as the main method to integrate the concepts of engineering, sustainable urbanism, fabricated in architecture, and sustainable residential megastructure engineering. Literature review is carried out through the planning stage (formulating research questions about the sustainability of vertical housing), data collection (literature search from the Scopus database and Google Scholar for the period 2020-2026 (Kurniawan & Pratiwi, 2021) with keywords such as "sustainable megastructure engineering" dan "prefabricated urbanism"), Title/abstract screening, as well as extraction of relevant data. Descriptive analysis is then applied to factually describe patterns, trends, and relationships between concepts without statistical hypotheses, resulting in a comprehensive narrative synthesis.

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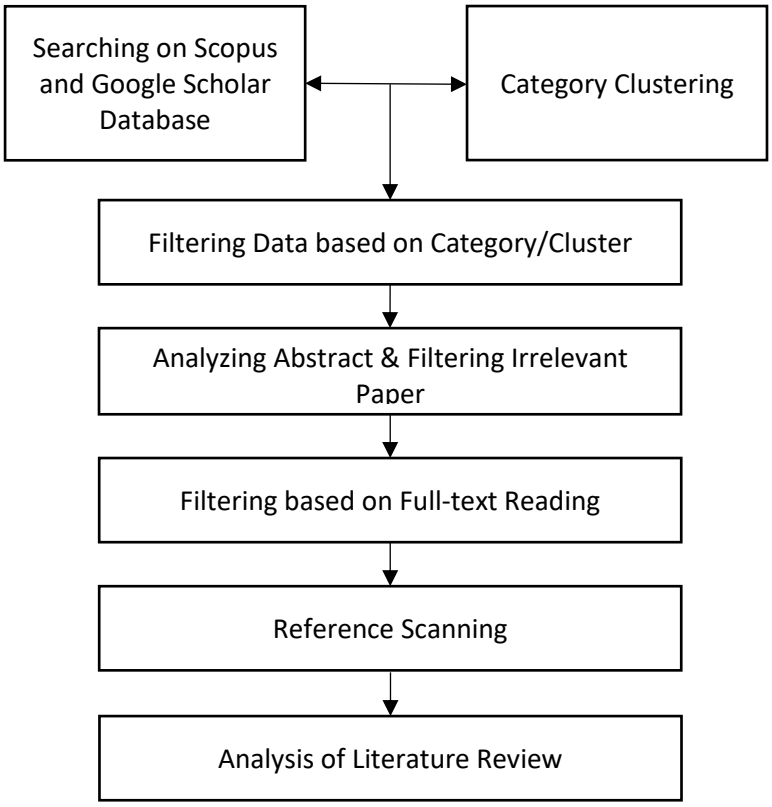

Graphic 1. Literature Review Flowchart
Source: (Ivanov, Hosseini, & Dolgui, 2019)

Descriptive analysis stage (Miles, Huberman, & Saldaña, 2021) includes grouping the literature findings into key themes, such as the efficiency of prefabricated fabrications in engineering and their impact on green open spaces, as well as the identification of long-term sustainability patterns of sustainable urbanism (Astita, 2025). This process involves a qualitative description of global research developments, including publication productivity and trends on topics such as green infrastructure and climate-resilient design, with a simple visualization in the form of a thematic table to map the contribution of each concept. This approach ensures a realistic representation of the phenomenon of residential megastructures that maintain a "blue sky" in the midst of natural disasters.

The purpose of this paper is expected to produce urban industrialization modeling with a *mega city, green city* approach with the concept of balanced housing between high, middle and low income people.

3. RESULTS AND DISCUSSION

3.1 The Dynamic Urbanism

Physical urban area (Smith, 2007) will be placed under a continuous movement or an eternal continuous motion, resulting from human movement and activity. Time becomes part of the physical dimension, and the user will be included as the creator of the urban landscape, with designers and planners, and true democracy can be achieved in the scale of dynamic urbanism, which will bring about change at all scales: urban, environmental, and individual.

3.2 The Ever-Changing Urban Environment: The Fourth Dimension

On an urban scale, time is never seen and substantial. The urban environment becomes a real demonstration of the passing of time and the events that occur are a reflection of the

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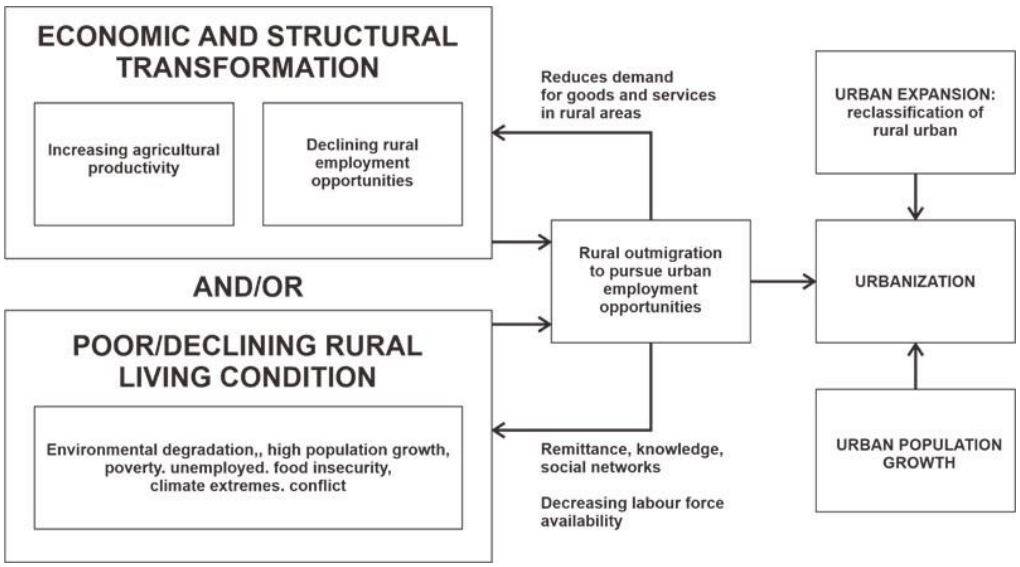
needs of users (Food and Agriculture Organization of the United Nations, 2023) in substantially different time periods. Regarding the description of the urban landscape, the year or the season will no longer be appropriate enough to use, and weeks or even days will be an appropriate measure to describe an urban area; The effect of time is so great. With the ambition to reshape the entire city, some avantgarde proposals articulate the flow of time.



Graph 1. Urbanization Triggers
(Sumber: Food and Agriculture Organization of United Nation, 2023)

To ensure the mobility and flexibility of the environment for changing humans, a common foundation of various theories and efforts can be found: introducing microstructures or parent structures into the environment to carry living modules. Compared to the ever-changing living unit, the matrix is relatively static. But the growth of the group form only occurs at a lower rate, rather than being completely corrected. Time can be witnessed not only by the clock, but also by the transformation of the city.

3.3 Sustainable Urbanism and Fabrication in an Urban Context

The manufacturing in question is the industrialization of hybrid modular systems (Makuch, 2016) which has four stages of manufacture: 1) *Put*: the module is industrially made off-site, 2) *Place*: The main structure of the building is designed to adapt to the development of the needs of the occupants, 3) *Plug*: the module can be easily attached to the main structure without additional construction work, and 4) *Play*: Developers and users can order modules as needed. These four stages, when viewed from an economic point of view, can be said to be *cost-effective* (Zullaile, Sarpin, Omar, Masrom, & Ismayatim, 2021) (Prasojo & Fatima, 2025). The industrial system in the manufacture of building modules also leads to a significant reduction in the destruction of nature, especially on the site. Building modules (Correira, 2017) is only made to meet the needs of the user, and the manufacture is not on site, thus saving labor and material costs significantly. According to Makuch (2016), this modular construction system is proven to reduce material waste by 90%, and save construction process costs by 20%. This figure is considered significant, so it can be well received by developers (Kusumowardani, 2021).

3.4 Urban Sustainable and Fabricated Relationships in an Urban Context

Based on the concepts and ideas of the two approaches to be used as a basis for sustainable residential megastructure planning, it can be concluded in the following table:

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Tabel 1. Konsep/Ide Sustainable dalam Fabricated in Urban Context

	Sustainable Urbanism	**Fabricated in Urban Context**
Konsep/ Ide	*Society Based*	Scaled: Urban, Neighborhood and Individual
	Complexity-led	Integrated area of TOD concept with good affordability
	Landscape-Driven Design Approach	Diperhatikan untuk mencapai *sustainable*

(Sumber: Rob Roggema, 2017 dan Penulis, 2026)

Throughout history, proximity has been a priority, implemented as a strategy that allows proximity and easy access in urban spaces to essential commercial, recreational and transportation services (Moreno, Allam, Chabaud, Gall, & Pratlong, 2021) (Megahed, Elshater, Afifi, & Elrefaie, 2024). In this case, for example, the city of Jakarta, the transportation system in various forms makes it easier for all people to travel from point A to point B at a relatively low cost. The existence of TOD in Jakarta makes logistics movement from inside to outside the city and from outside the city easy, cheap and effective (Saragih, Bahagia, Suprayogi, & Syabri, 2015) (Hanafiah, Ilham, & Liswandi, 2025). Sustainable relationships and hybrid modular fabrication in urban contexts offer significant benefits through the industrialization of hybrid modular systems (Makuch, 2016) which includes four stages: 1) Put: the module is industrially manufactured off-site for factory efficiency, 2) Place: the main structure is designed flexibly to adapt to the dynamics of urban needs, 3) Plug: quick module installation without additional construction, and 4) Play: customization of the module according to user request. This approach supports sustainable urbanism by reducing carbon emissions through controlled production, minimizing urban traffic disruptions, and enabling rapid adaptation to population growth (Zullaile, Sarpin, Omar, Masrom, & Ismayatim, 2021). "This system has been proven to reduce material waste by up to 90% and construction costs by 20%," thus accelerating the provision of vertical housing for TOD such as Rusunawa Pasar Rumput and Rusunawa Jatinegara Barat Jatinegara in Jakarta (Prasojo & Fatima, 2025) (Correira, 2017).

However, the application of hybrid modular fabrication in an urban context poses neutral challenges related to supply chain coordination and local regulations in Jakarta. Although the Put stage ensures the quality of the factory, the reliance on the transportation of large modules to the TOD site is potentially hampered by narrow road infrastructure and the bureaucracy of DKI licensing (Kusumowardani, 2021). The Place and Plug stages require a high-precision master structure design, while the Play stage relies on a digital ordering platform that is not mature in Indonesia, requiring significant initial investment with no guarantee of mass adoption (Makuch, 2016). This creates a balance between cost-effective efficiency and the need to adapt to the local context (Zullaile et al., 2021).

On the other hand, the negative risks of hybrid modular fabrication that are and will occur include module incompatibility with Jakarta's tropical climate, such as corrosion due to high humidity at the Plug and Play stage. Off-site production in the Put stage can increase transportation emissions if the plant is far away, contrary to the sustainability goals of the TOD, while the Place stage is vulnerable to vertical residential demand uncertainty due to economic fluctuations (Correira, 2017). Further criticism highlights the lack of local skilled labor for post-construction maintenance, which has the potential to raise long-term

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operational costs by up to 15% above initial projections (Prasojo & Fatima, 2025) (Kusumowardani, 2021).

3.5 The Relationship between Sustainable Fabricated Urbanism and the TOD Housing Concept

Padre (2017), in ITDP (Padre, 2017) states that the main principles that must exist in residential planning with the concept of TOD are as follows:

1. *All* roads within the TOD area support safe and complete walking, protected from the sun and rain. Including direct access to each building.
2. *Cycle*/Cycling.The bicycle infrastructure network is available completely and safely (protected from motorized vehicles), from access to bicycle lanes to bicycle parking that is available in sufficient quantities.
3. *Short* walking and cycling routes (shorter than motor vehicle routes), direct and varied, including the elimination of fences and *perimeter walls*.
4. *Transit*/Public Transportation.Mass public transportation stations within walking range.
5. *Mix*/Mix.Mixed/Mixed.Mixed-use land *use* or residential areas that unite various functions, both for residential and non-residential areas, at least in one block or next to each other. Thus, the walking distance becomes shorter, including heading to public spaces.
6. Densify.The high density of residential and non-residential areas supports high-quality transportation, local services, and public space activities. That way it can be ensured that all residents have access to public transportation.
7. *Compact*/Close.Focus development on areas that have been built, not suburban areas, so that more public transportation routes serve the TOD area. That way, residents in the area and outside the area can live close to schools, offices, and service centers which will certainly reduce traffic congestion.
8. *Shift*/Shift.Reduction of land used for motor vehicles. It is recommended that the total area of parking space provided (including parking buildings and *basements*) should not exceed 35% of the total residential area.

The Relationship of Sustainable Fabricated Urbanism with the Concept of Housing TOD integrates hybrid modular fabrication (Makuch, 2016) into the principles of Walk, Cycle, Connect, Transit, Mix, Densify, Compact, and Shift to create vertical residences such as Rusunawa Pasar Rumput and Jatinegara Barat that are efficient and sustainable in Jakarta. In the Put and Plug stage, the prefabricated module enables the design of Walk/Walk infrastructure with a closed pedestrian corridor directly to the MRT station, as well as Cycle/Cycling with safe lanes integrated with flexible structures (Place), reducing construction emissions by up to 90% while supporting Transit/Public Transportation access in radius 500 meters (Zullaile, Sarpin, Omar, Masrom, & Ismayatim, 2021). The concept of Mix / Mix and Densify / Compact is strengthened by the Play stage which facilitates vertical mixed-use with market stalls and public facilities, compacting the population up to 300 people/ha without the expansion of suburban land (Compact), so that Shift / Shift succeeds in limiting motorized parking to below 35% (Prasojo & Fatima, 2025).

The application of fabricated modular in the TOD framework results in a neutral synergy where the Connect/Connect stage utilizes short pedestrian routes without perimeter walls through customizable plug-and-play modules, although it requires precise coordination between off-site factories and Jakarta's dense urban footprints. Compact/Close in existing areas such as West Jatinegara utilizes the main structure (Place) for high densification, supports the mix of residential-non-residential functions adjacent to each other, but relies on

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a stable supply chain to maintain the Transit integration schedule (Correira, 2017). This creates a balance where a 20% reduction in waste costs supports the shift of reducing parking spaces, but demands adaptation of Jakarta regulations for protected Cycle and Walk infrastructure (Kusumowardani, 2021). However, negative risks arise when modular hybrid fabrication collides with the tropical climate of TOD Jakarta, where the Plug stage on the Walk/Cycle is prone to modular leakage due to heavy rain, disrupting access to Transit and Mix daily functions. High densifies in compact areas such as the Grass Market has the potential to overload the Place structure if Play demand exceeds projections, increasing maintenance costs by 15% and making it difficult to shift motorized parking restrictions below 35% (Makuch, 2016). Further criticism highlights the lack of flexibility of the Connect pedestrian route if the module fails to adapt to urban informal growth, potentially leading to long-term sustainable inefficiencies (Prasojo & Fatima, 2025).

3.6 Vertical Housing with TOD approach in Jakarta

3.6.1 TOD areas in Jakarta

Vertical residences of the TOD concept in Jakarta, such as Rusunawa Pasar Rumput and West Jatinegara, realize sustainable urbanism through the integration of high-density public transportation access, reduce dependence on private vehicles and optimize limited land in the capital city. A modular hybrid fabricated approach (Makuch, 2016) supports efficiency with Put (off-site production), Place (flexible structure), Plug (quick installation), and Play (customization) stages, minimizing waste by up to 90% and costs by up to 20% while providing mixed-use facilities such as kiosks, parks, and enclosed pedestrian corridors. "This modular system has proven to be cost-effective in a dense urban context," accelerating the provision of affordable housing for MBRs near MRT stations and terminals (Zullaile, Sarpin, Omar, Masrom, & Ismayatim, 2021) (Prasojo & Fatima, 2025).

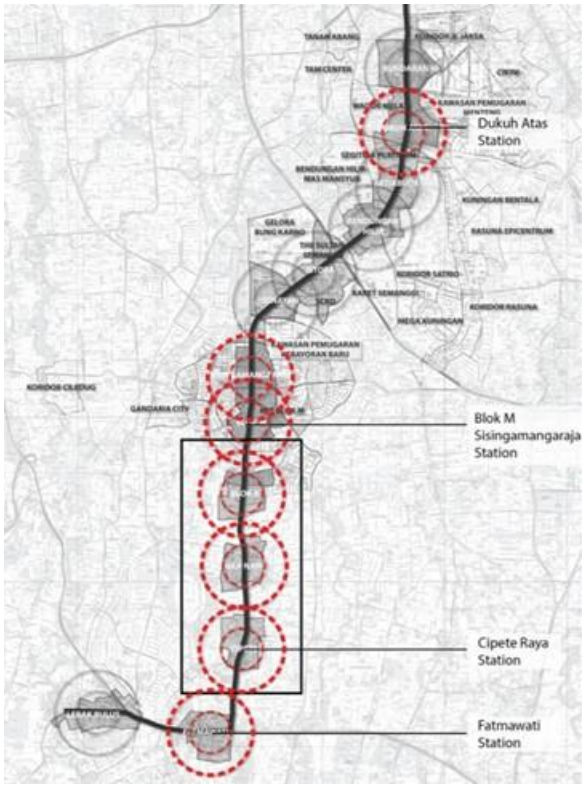

Figure 1. TOD in Jakarta
Source: (Sofa & Hanggara, 2023)

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The implementation of this vertical TOD is in line with the principles of Walk, Cycle, Connect, Transit, Mix, Densify, Compact, and Shift, where Rusunawa Pasar Rumput integrates 1,984 units above the traditional market with a short walking distance to the MRT, while West Jatinegara condenses 520 units in the existing area to support mass transportation and motorized parking restrictions below 35%. Fabricated modular facilitates the mix of adjacent residential-non-residential functions as well as secure cycle infrastructure, although it requires precise supply chain coordination to maintain transit access within a 500-meter radius. This neutrality creates a balance between industrial efficiency and adaptation of DKI Jakarta regulations (Correira, 2017) (Kusumowardani, 2021).

However, negative challenges include the risk of module mismatches to tropical climates, such as corrosion in the Plug stage due to heavy rains disrupting the Walk/Connect route, as well as the potential for Densify overload in the Compact area if Play demand exceeds projections, increasing maintenance costs by up to 15%. Critics highlight the lack of local skilled labor for post-construction maintenance, which has the potential to lead to inefficiencies, shifts, reduced parking lots, and reliance on remote module transportation, which is contrary to TOD's sustainable goals. However, the long-term potential remains high with sustainable adaptation (Makuch, 2016) (Prasojo & Fatima, 2025).

3.6.2 Grass Market Flats

Rusunawa Pasar Rumput as a vertical residence for TOD in Jakarta integrates fabricated modular hybrid (Makuch, 2016) with 1,984 units above 1,314 traditional market stalls near MRT stations, supporting sustainable urbanism through closed walking/walking and safe cycle access that reduces emissions by up to 90% via Put (off-site) and Plug (quick installation) stages. Mixed-use facilities such as PAUD, clinics, and parks strengthen Mix/Mix and Densify/Compact areas, allowing Shift/Switch with motorized parking below 35% (Zullaile, Sarpin, Omar, Masrom, & Ismayatim, 2021). Modular systems are proven to be cost-effective up to 20% more economical, accelerating Transit/Public Transportation for MBR (Prasojo & Fatima, 2025).

Figure 2. Modular Facade of Rusunawa Pasar Rumput
Source: Author, 2019

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This implementation creates a neutral synergy where Connect/Connect short pedestrian routes without perimeter walls utilize the Place stage (flexible structure), although precise supply chain coordination is required to maintain the Mix of adjacent market-residential functions. The integrated Cycle infrastructure supports Densify 300 people/ha, but relies on Jakarta regulations for transit access of a radius of 500 meters without modular logistics disruptions (Correira, 2017). This balances industrial efficiency with Jakarta's urban adaptation (Kusumowardani, 2021).

Negative challenges include modular corrosion of the Plug stage due to tropical rains disrupting the Walk/Connect to the MRT, as well as the potential for Densify overload if Play demand exceeds projections, increasing maintenance costs by 15%. Module transport is far at odds with Shift reduced parking, while lack of local skills makes long-term maintenance difficult in Compact areas (Makuch, 2016). This criticism has the potential to cause ongoing inefficiencies (Prasojo & Fatima, 2025).

3.6.3 West Jatinegara Flats

West Jatinegara Rusunawa applies the concept of vertical TOD with two 16-storey towers (520 units) (Leepel, Utomo, & Suganda, 2020) near Terminal Kampung Melayu, utilizing hybrid modular fabrication for safe Walk/Walk and Protected Cycle/Cycling that saves 90% waste through the Put and Play stage customization. The integration of extensive RTH, PAUD, and health centers strengthens Mix/Mixing and Densify in Compact areas, supports motorized parking shifts <35% and mass transit access (Zullaile, Sarpin, Omar, Masrom, & Ismayatim, 2021). This approach compacts efficient populations for sustainable urbanization, ideal for MBR relocation (Prasojo & Fatima, 2025).

Figure 3. Modular Facade of Rusunawa Jatinegara Barat
Source: Author, 2019

A neutral aspect is seen in the Connect of the various routes without fences via the flexible Place stage, facilitating a mix of adjacent residential-non-residential even though it requires the precision of off-site logistics in East Jakarta. High densify aligns with existing Compact, yet the digital Play platform is not yet ripe for module booking, balancing efficiency with local regulations (Correira, 2017). Ini menuntut investasi awal untuk infrastruktur Cycle/Transit optimal (Kusumowardani, 2021). Negative risks include Plug stage modular leaks in humid climates that inhibit the Walk to the terminal, as well as the uncertainty of Play demand that puts a high burden on the Place structure in Densify. Module transportation

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increases emissions, colliding with Shift, while minimal local skills have the potential to increase operational costs by 15% (Makuch, 2016). This threatens the long-term sustainability of TOD (Prasojo & Fatima, 2025).

4. CONCLUSION

In planning sustainable fabricated urbanism with the concept of TOD, the combination of principles such as Walk, Cycle, Connect, Transit, Mix, Densify, Compact, and Shift with hybrid modular fabrication (Put, Place, Plug, Play) is the main key to creating efficient vertical housing such as Rusunawa Pasar Rumput and West Jatinegara in Jakarta. This approach not only ensures the selection of strategic locations near mass transportation infrastructure, but also adopts off-site fabrication that reduces waste by up to 90% and costs by up to 20%, while supporting sustainable densification without sacrificing safe pedestrian access or functional mixed-use. The foundation of sustainable development is reflected in the priority shift of reducing motorized parking spaces below 35%, which strengthens ecological and economic integration in dense urban contexts.

However, implementation requires a balanced contemporary paradigm, where further research should explore the adaptation of fabricated modular to Jakarta's tropical climate, such as corrosion resistance at the Plug stage and Place flexibility for Play demand dynamics in the Compact area. This new paradigm must consider precision supply chain coordination to avoid the risk of Densify overload or increased module transportation emissions, while balancing cost-effective efficiency with local regulations that often hinder Connect of varied routes. Thus, large-scale settlement construction in the TOD area can be a model that is not only resource-efficient, but also responsive to neutral challenges such as the maturity of digital platforms for MBR residential customization.

Furthermore, the new paradigm in the development of TOD areas must place ecological elements intact as a priority, including the integration of biophilic roof gardens and vertical RTH to compensate for the impact of high densify and support the mix of daily functions without perimeter expansion. Future research is needed to measure the long-term impact of fabricated urbanism on reducing congestion and improving quality of life, with a focus on training local workers to minimize maintenance costs by up to 15% post-construction. This holistic approach will make TOD Jakarta a global benchmark for sustainable urbanism that balances industrial innovation, environmental sustainability, and social inclusivity.

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