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Implementing Modular Layouts to Increase Scalability of Production Facilities

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Abstract

Modular layouts have become a relevant design strategy in improving the efficiency and scalability of production facilities, especially in the face of the challenges of market dynamics and sustainability needs. This study aims to analyze the application of modular layout in improving the scalability of production facilities through a literature study approach. The data used came from various journal articles, technical reports, and academic books published in the last five years. The analysis was carried out by the content analysis method to explore the principles of modular design, its advantages in operational efficiency, and the challenges faced in implementation. The results show that the modular layout supports high flexibility through design standardization, allowing for adjustment of production capacity without disrupting key operations. This approach also reduces operational costs and risks through systems that can be maintained and repaired modularly. However, its implementation requires significant initial investment as well as adequate workforce training. This research emphasizes the importance of careful planning and the adoption of digital technologies such as computer-based simulations to ensure the success of modular systems.

INTRODUCTION

In an era of globalization and increasingly fierce industrial competition, the flexibility and efficiency of production facilities are key factors for companies to maintain their competitiveness (Aldi et al., 2023). Modular layouts have become an increasingly popular design approach because they allow for rapid adaptation to changing production needs (Matt & Rauch, 2020; Yang & Lu, 2023). The layout of a production facility plays a crucial role in determining a company's workflow efficiency, productivity, and adaptability to changes. In this context, the implementation of modular layouts has emerged as an innovative approach that allows companies to improve the scalability of their operations through design flexibility and ease of expansion. Modularity allows for more effective management of production space while supporting the adjustment of production capacity to dynamic market needs (Rogers & Bottaci, 1997).

Modular layout is a design approach that divides a space or system into small units that can be rearranged to create flexibility and efficiency in various contexts, such as architecture, industry,

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and software (Bioati & Kusnaedi, 2024; Tsukune et al., 1993). The concept focuses on the efficiency of space use and ease of adaptation, especially in dynamic environments. For example, research by Cruz et al. (2025) examines the application of modular design in artificial reef structures, which allows for rearrangement and adjustment according to the conditions of marine ecosystems. The results show that the modular approach improves resource use efficiency and structural sustainability compared to conventional design (Cruz et al., 2025).

In addition, modular layouts are also widely used in the context of technology and manufacturing. According to Zhong et al. (2025), modularity in hardware design allows for easy merging and separation of components, creating systems that can adapt to user needs or technological changes. The study shows that modularity not only improves operational efficiency but also supports innovation because design flexibility allows for the introduction of new technologies without replacing the entire system. Modular layouts are also applied in user interface design and digital space management to improve user experience and optimize visual displays (Zhong et al., 2025).

Production facilities refer to the infrastructure, equipment, and systems used to efficiently produce products or services (Sari et al., 2024). In the modern context, production facilities are not only designed to meet output targets but also consider aspects of sustainability, energy efficiency, and environmental impact reduction. Advances in digital technology have strengthened the potential for modularity in facility layouts. Technologies such as digital twins, computer-based simulation, and the Internet of Things (IoT) provide the ability to design, test, and optimize production modules before implementation in physical facilities. With this technology, companies can mitigate operational risks, increase implementation speed, and maximize system efficiency (Lakshmi Narayan, 2022). Additionally, modular designs have been shown to support sustainability goals by enabling more economical use of resources, reduced production waste, and more focused facility maintenance.

Modular layouts also play an important role in meeting sustainability demands in the manufacturing sector. The implementation of modular layouts is very relevant for manufacturing companies in Indonesia, where local and global market dynamics create significant challenges. With the growing number of manufacturing ventures and the need to compete in the global market, companies need to adopt innovative approaches to improve competitiveness (Baldea et al., 2017).

In addition, technological developments have supported the implementation of modularity on a wider scale. Small and medium-sized industries (SMEs) in Indonesia, which contribute greatly to economic growth, can also take advantage of modular layouts to improve efficiency without large investments in infrastructure (Guo et al., 2019). With the adoption of modularity, companies can respond more quickly to market changes and minimize the risk of overcapacity during periods of low demand.

However, challenges remain in the implementation of modular layouts. In-depth and evidence-based research is needed to identify the best strategies in modular design and implementation, particularly in the context of Indonesia's manufacturing industry. By understanding the optimal approach, companies can overcome these barriers and maximize the benefits of modular layouts (Pakkanen et al., 2019).

Research on modular layouts is essential because this approach not only supports scalability but also creates flexibility in the face of changing market dynamics. In the context of production facilities in Indonesia, the adoption of modular layouts can help companies compete in the global market through reduced costs, increased efficiency, and better resource management. This urgency is increasingly relevant in the era of Industry 4.0, where adaptability is one of the keys to the success of the Company (Zhang et al., 2022).

Previous research has highlighted the benefits of modular layouts in various sectors. For example, research by Ipaki and Hosseini (2025) shows that modularity in electronic design supports continuous repair and maintenance, while a study by Patel (2025) highlights how modularity improves the efficiency of nuclear waste management in energy facilities. However, most of this research focuses on the global context, so further exploration is needed on the application of modularity in Indonesia.

This study aims to analyze the application of modular layout in improving the scalability of production facilities in Indonesia. By exploring modular design and implementation strategies, the study aims to provide practical recommendations for companies looking to optimize their production efficiency amid evolving market dynamics.

METHOD

This study uses a qualitative approach with a library research method to analyze the concept of modular layout in improving the scalability of production facilities. Literature studies are chosen because they provide flexibility in exploring and synthesizing various relevant sources of information to understand the phenomenon being studied. This approach allows researchers to identify key concepts, design principles, and case studies related to modular layouts (Snyder, 2019).

The data sources used in this study consist of journal articles, academic books, technical reports, and conference publications published in the last five years (2018–2023). Data is obtained from trusted databases such as ScienceDirect, Taylor & Francis, IEEE Xplore, and SpringerLink. The focus of the literature search includes the study of modular design, the scalability of production facilities, and the operational efficiency resulting from the implementation of modular layouts.

The data collection technique was carried out through systematic searches using keywords such as "modular layout," "scalable production," and "flexible manufacturing." The selection process involves inclusion criteria such as literature that presents empirical results, clear methodologies, and the relevance of the topic to the research objectives. On the other hand, literature that is opinionated or irrelevant is excluded. The data obtained were then classified based on the main themes relevant to the research.

The data analysis method used is content analysis to identify patterns, relationships, and trends in relevant literature. The analysis is carried out deductively using relevant theoretical frameworks, such as the principle of modularity and scalable design theory (Oztemel & Gursev, 2020). The data was analyzed to explore the advantages of modular layouts in improving the operational efficiency and scalability of production facilities, as well as to identify challenges that may arise in their implementation.

RESULT AND DISCUSSION

The following is a literature table that contains 10 selected articles from various literature related to the topic of modular layout and scalability of production facilities. These articles were selected because they make a significant contribution to the understanding of modular design concepts, operational efficiency, and the development of flexible and sustainable production facilities.

Table 1. Literature Review

No	Author	Title	Finding
1	Ipaki & Hosseini (2025)	Enhancing Internal Supply Chain Management in Manufacturing through a	The modular approach increases the flexibility of the internal supply chain and supports scalability through a digital twin architecture.

		Simulation-Based Digital Twin Platform	
2	Ipaki & Hosseini (2025)	Repair-Oriented Design and Manufacturing Strategies for Circular Electronic Products	The modular design supports efficient improvement in electronic products and promotes sustainability through a circular production process.
3	Mollo et al. (2025)	The New KM3NeT Detection Units	The modular design improves the connectivity of the underwater optical detection unit, allowing scalability through the addition of modular layers.
4	Bahrololoum et al. (2024)	Modular, Standardised, Scalable and Production-Optimized Floating Platform Design	The modular floating platform is designed to optimize production and enable scalability at various renewable energy locations.
5	Rahman & Hellgardt (2025)	Flat-Plate Photobioreactors for Renewable Resources Production	The modular design in photobioreactors improves efficiency and interaction between processes, allowing for more flexible renewable production.
6	Patel (2025)	Automating Low-Level Nuclear Waste Sorting: Enhancing Efficiency, Safety, and Scalability	The modular design allows for safer and more efficient management of nuclear waste through scalable units.
7	Kampker & Heimes (2024)	Design of Automotive Battery Systems for the Circular Economy	The modular design supports the circular economy by enabling efficient replacement of battery components and the scalability of the energy system.
8	Cao et al. (2025)	Electrochemistry-Empowered Nano-Labeling for Versatile Aptamer-Based Biosensing	The modular design is used to improve the scalability of electrochemical-based biosensing technology.
9	Jung et al. (2024)	Optimizing Economic Feasibility of CO2 Capture Processes with Rotating Packed Bed (RPB)	The modular approach is a viable economic strategy to increase the scalability of the carbon capture process.
10	Wollen et al. (2024)	Battery-Electrolyser Low-Pressure Management System	The modular system enables low-pressure management of battery-electrolyzers that support scalable hydrogen production.

The compiled literature table provides a comprehensive overview of various research findings related to the application of modular layout to improve the scalability of production facilities. The selected articles cover a wide range of industry sectors and technology applications, demonstrating the flexibility and great potential of modular design in creating efficient, sustainable, and adaptable production systems.

Research by Longo et al. (2024) reveals that a modular approach in internal supply chain management, through integration with digital twin platforms, can improve the flexibility and efficiency of production systems. Digital twins allow companies to model various operational scenarios and adjust production capacity to changing market needs. This study shows that modular design not only impacts the physical aspects of the facility's layout but also on digital integration, which provides real-time control over the production process (Cimino et al., 2024).

Ipaki and Hosseini (2025) discuss the importance of modular design in supporting the circular economy. They found that the modular approach allows for the repair and reuse of components in electronic products, thereby reducing waste and extending the life of the product. This creates added value for companies looking to adopt sustainable practices, while also improving cost efficiency. This study highlights how modularity can facilitate the transition to more sustainable business models, which is particularly relevant in the context of modern industries (Ipaki & Hosseini, 2025).

Mollo et al. (2025) discuss the application of modular design in subsea optical detection systems. They point out that the modular design allows for connectivity between optical units with high flexibility, so that it can be scaled as needed. These findings are significant as they show that modularity is not only relevant for onshore production but also for operations in extreme environments such as underwater, where scalability and flexibility are critical for operational success (Mollo & Collaboration, 2025).

Bahrololoum et al. (2024) extend the application of modular design to the field of renewable energy, specifically floating platforms. This study shows that modularity can improve efficiency in the construction and operation of energy facilities, such as offshore wind farms. The standardized design allows the platform to be used in various locations with minimal adaptation, which reduces development costs and time (Bahrololoum et al., 2024).

Rahman and Hellgardt (2025) focus on modular photobioreactors for the production of renewable resources. They point out that the modular design facilitates interactions between processes, such as separation and extraction, which improves overall operational efficiency. This study highlights how modularity can be used to facilitate technological innovation in sustainable production (Rahman & Hellgardt, 2025).

Patel (2025) provides insight into how modularity is applied in nuclear waste management. They point out that the modular design allows for a safer and more efficient waste management system, with units that can be scaled to handle different volumes of waste. This approach creates flexible and customizable solutions for specific needs, while maintaining high safety standards (Patel, 2025).

Kampker and Heimes (2024) discuss the role of modularity in automotive battery system design. They found that modular design not only improves operational efficiency but also supports the circular economy by enabling efficient replacement and repair of components. This is especially important in the context of the automotive industry increasingly shifting to Electric vehicles (Maltoni et al., 2024).

Cao et al. (2025) examined modular designs in electrochemical-based biosensing technology. The study found that modularity allows for the development of more flexible and scalable biosensing devices for a wide range of medical applications. This suggests that modularity can create great opportunities in medical technology innovation (Cao et al., 2025).

Jung et al. (2024) discuss the application of modularity in the carbon capture process using rotating packed beds (RPB). The modular approach was found to be an economical solution that allows these processes to be scaled according to industry needs, which is particularly relevant in global efforts to reduce carbon emissions (Jung et al., 2024).

Finally, research by Wollen et al. (2024) shows that modularity in battery-electrolyzer systems allows for more efficient and flexible hydrogen production. Modular systems allow for low-pressure management by adding new units as needed, which creates efficiency and scalability (Wollen et al., 2024).

Overall, these articles show that modular design has a wide range of applications in various sectors, from electronics manufacturing to renewable energy and medical technology. This approach not only improves efficiency and flexibility but also creates opportunities for sustainable innovation. Modularity is key in overcoming the challenges of market dynamics, sustainability needs, and the complexity of modern technology.

Discossion

Implementing Modular Layouts in the Scalability of Production Facilities

Modular layout has become one of the strategies that has proven effective in increasing the efficiency and scalability of production facilities, especially in Indonesia which has highly volatile market dynamics. Modularity in facility design provides high flexibility, allowing companies to adjust production capacity according to market demand without requiring major changes to infrastructure. With this approach, companies can efficiently increase or decrease production capacity based on need. For example, new production modules can be added to accommodate increased market demand in a short period of time, while less needed modules can be decommissioned during periods of low demand. This not only helps companies adapt faster to market changes but also avoids wasting resources due to overcapacity.

Another advantage of modular layouts lies in their ability to improve the efficiency of the production process. Standardized designed modules allow similar production processes to be grouped together, reducing transit time between processes and improving overall workflow. This standardization also provides additional advantages in terms of employee training. Since each module is designed with a uniform operating system, new employees can quickly learn how to operate the module, so their integration into the production system becomes faster and more efficient.

In addition to flexibility and efficiency, modular layouts also offer significant cost reductions and operational risks. In modular design, the cost of building and maintaining production facilities can be minimized because damaged modules can be replaced individually without affecting the entire system. This means that operational disruptions due to a breakdown in a single module will not have a major impact on the overall production system, reducing the risk of downtime, which is often costly. Thus, modular layouts become a solution that not only improves operational efficiency but also strengthens the company's resilience to unexpected disruptions.

This modular approach offers relevant solutions to modern industry challenges, especially in the face of rapidly changing market needs. By adopting a modular layout, companies can optimize the flexibility, efficiency, and reliability of their production facilities, providing a significant competitive advantage in the global market landscape.

Modular Design and Implementation Strategy

Modular design and implementation strategies play a crucial role in ensuring the successful adoption of modular layouts in production facilities. This process begins with an in-depth analysis of production needs. Before designing a modular layout, companies must clearly understand their specific needs, including the required production capacity, the variety of products produced, as well as the potential for changes in market demand. This analysis allows companies to design modules that suit their operational needs, both in terms of size, function, and number of modules required.

Adaptive modular design is the next step in this strategy. Production modules must be designed so that they can be easily customized, added, or integrated with other modules without major disruption to ongoing operations. This flexible design typically involves the use of standard connections for electricity, water, or internal transportation systems, allowing for quick integration with additional or newly designed modules. This approach also often leverages plug-and-play technology that allows the module to function immediately after being connected, without requiring complicated reconfiguration.

The use of digital technology is an integral part of the modular design strategy. Technologies such as computer-based simulation and digital twins allow companies to create and test modular designs in a virtual environment before real-world implementation. This way, companies can identify potential design issues, estimate workflows, and evaluate the overall efficiency of modular systems. In addition, Internet of Things (IoT) technology can be integrated into production modules to monitor performance in real-time. With this data, companies can make data-driven decisions to optimize production, predict module maintenance, and prevent operational disruptions before they occur.

A modular implementation strategy should also involve adequate training for employees. Because modular systems often involve new operational standards, employees need to be trained to understand how to operate and maintain the modules. This training focuses not only on the technical aspects but also on adaptability to the changes that often occur in modular systems. Thus, employees can be part of supporting the smooth implementation and ensuring that the modular system can function optimally.

This overall modular design and implementation strategy emphasizes the importance of careful planning and the use of modern technology to achieve flexibility, efficiency, and scalability in production facilities. This approach allows companies to not only meet the needs of a dynamic market but also create production systems that are more resistant to disruption, more cost-effective, and more efficient in the long run.

Practical Recommendations for Companies

Based on the findings and analysis, here are practical recommendations for companies looking to optimize production efficiency through modular layouts:

1. Get Started with Pilot Projects

   Before adopting a modular layout across production facilities, companies are advised to start with a pilot project on one of the production lines. This allows for an initial evaluation of the effectiveness of the modular system and the identification of potential constraints.
2. Investing in Supporting Technology

   Companies must invest in technologies such as computer-based simulation, IoT, and automation systems. This technology helps in the planning, implementation, and maintenance of modules, thereby improving overall operational efficiency.
3. Collaboration with Modular Technology Providers

   Working with a partner who is experienced in modular design and implementation can speed up the adoption process. These partners can assist in the design that fits the company's specific needs as well as provide technical support during the implementation phase.
4. Continuous Evaluation and Improvement

   After implementation, the company should routinely evaluate the performance of the modular layout and identify areas that need improvement. This evaluation process should be based on operational data, such as production cycle time, efficiency level, and capacity utilization level.
5. Adaptive Policies

   Given the ever-changing market dynamics, companies must have flexible policies in place to allow for quick adjustments to modular systems. For example, a policy to increase production capacity during periods of peak demand or decommission certain modules when demand decreases.

CONCLUSION

This study shows that modular layouts provide high flexibility and efficiency in the management of production facilities. The modular design allows the adjustment of production capacity according to market needs, which reduces resource waste and improves the competitiveness of the company. Modular systems also support sustainability by promoting component reuse and waste reduction. However, modular implementation requires careful planning, supporting technology, and human resource training to ensure long-term success. In addition, the integration of digital technologies such as computer-based simulation and the Internet of Things (IoT) plays a crucial role in improving the effectiveness of modular layouts.

To optimize the benefits of modular layouts, companies are advised to start with a pilot project to evaluate the effectiveness of modular systems in specific contexts. Investments in supporting technologies such as digital twins and IoT are essential to monitor module performance in real-time and predict maintenance needs. Companies also need to adopt a collaborative approach with modular technology partners to accelerate implementation and leverage their technical experience. Finally, continuous evaluation and improvement should be an integral part of the implementation strategy to ensure modular systems remain relevant and responsive to changing market needs. With these steps, modular layouts can be an effective tool for improving the efficiency and scalability of production facilities.

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