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A comprehensive review of facility layout planning under uncertainty: Methodologies, trends, and future directions

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A B S T R A C T

Facility Layout Planning (FLP) is one of the most important strategic decisions that have a very big effect on the operational efficiency and therefore also the productivity and cost-effectiveness of manufacturing and service systems. The uncertainty which is inherent to the parameters like product demand, material flow, and processing times makes the FLP problem very complicated and dynamic. This paper exhibits a detailed review of the works done so far on FLP under uncertainty which has been based on an analysis of 163 articles from the Scopus database. The review organizes and evaluates systematically the main methodologies used, among them mathematical programming, heuristics and metaheuristics, simulation, and Multi-Criteria Decision-Making (MCDM) methods. The different types of uncertainty—fuzzy, stochastic, robust, and fuzzy-random—being modeled and integrated into solution approaches is one of the main areas of focus. It turned out from the analysis that hybrid metaheuristics, especially when combined with fuzzy MCDM techniques, are the most common and effective means of dealing with fluoroscope FLP issues today. Moreover, the paper contains a bibliometric analysis that underlines the main contributors, geographical patterns, and the trend of shifting research emphasis toward topics like construction site layout, sustainable logistics, and digital twin-supported planning. The review not only presents the gaps in the current literature but also points to further research implications including more integrated use of AI and dealing with the problem of real-time dynamic layout reconfiguration.

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1. Introduction

Facility Layout Planning (FLP) is one of the most important elements in industrial engineering and operations management, dealing with the best positioning of physical resources like machines, departments, workstations, and other assets inside a building. The main aim is to cut down material handling costs, shorten production time, improve workflow, and benefit the system as a whole (Tompkins et al., 2010). An efficient layout can achieve great cost savings in operation while a bad one can be a source of bottlenecks that increase the work-in-process inventory and block the flexibility of operation. The traditional FLP issue is in itself quite complicated and has been shown to be NP-hard (Kouvelis et al., 1992). Real-world settings further complicate this situation because of the uncertainty that is common in such environments. Usually, the most important input factors are not very accurately known. For example, demands for products might change in an unexpected manner, the time needed for material handling could also change, and the links between different departments might be judged subjectively and qualitatively. Besides, the ever-increasing market demand for mass customization and fast technological advancements require layouts that are not only optimal for a particular set of conditions but are also robust or dynamic allowing them to adapt to changing conditions over time.

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Conventional deterministic FLP models, which treat all parameters as known and stable during the entire process, are usually insufficient to represent the day-to-day operation of today's production and service systems. As a result, researchers have been adopting different paradigms for dealing with uncertainty, which led to the birth of an extensive research field. These are:

- **Fuzzy set theory** to model linguistic vagueness and imprecision.
- **Stochastic programming** and **probabilistic models** to address randomness with known distributions.
- **Robust optimization** to generate solutions that are immune to data uncertainties.
- **Scenario-based planning** to evaluate performance across multiple possible futures.

The primary goal of this paper is to systematically and comprehensively review the prevailing situation in FLP under uncertainty. The review is based on a carefully selected dataset consisting of 163 academic papers and intends to:

1. Quantify and analyze the adoption rates of various techniques (e.g., exact methods, metaheuristics, simulation).
2. Classify and verify the various strategies for modeling uncertainty (fuzzy, stochastic, robust).
3. Study the role of Multi-Criteria Decision-Making (MCDM) methods in assessing and choosing layout alternatives.
4. Provide a bibliometric overview of the field, identifying leading contributors, influential papers, and global research trends.
5. Synthesize the results to determine current challenges and propose future research directions.

The remainder of this paper is structured in such a way that Section 2 describes the review method used. Section 3 gives an overview of the FLP problem and uncertainty. Section 4 gives a comprehensive discussion on the solution methods. Section 5 is dedicated to uncertainty management strategies. Section 6 examines the use of MCDM. Section 7 presents a bibliometric analysis. Section 8 points out the areas of research that have not been covered and the directions for future research, while Section 9 wraps up the paper.

2. Review Methodology

This review is according to a targeted analysis of a provided dataset containing 163 papers exported from the Scopus database. The search query was designed to capture the core intersection of layout planning and uncertainty handling: "facility layout planning" OR "layout planning" AND ("uncertainty" OR "robust optimization" OR "fuzzy" OR "stochastic").

The analysis was conducted in a structured manner:

1. **Categorization:** The classification of each paper was done according to its main methodological approach (for instance, Genetic Algorithm, Fuzzy AHP), type of uncertainty tackled (for instance, fuzzy, stochastic), and application area (for instance, manufacturing, construction).
2. **Quantitative Analysis:** The trends and dominant paradigms mixed in the corpus would be discussed to know them closely, calculate the proportion, and count for the little snapshot study.
3. **Qualitative Synthesis:** In-depth analysis was performed on the highly cited and representative papers to comprehend the subtleties of their contributions and the progression of ideas through time.
4. **Bibliometric Mapping:** Information such as authors, affiliations, countries, and citation counts were extracted and used for a study of the intellectual landscape in this context.

The mixed-methods strategy of quantitative and qualitative research provides a solid picture of the study area, revealing the most widely used methods, their reasons for success, and the situations in which they are used.

3. Background on Facility Layout Planning and Uncertainty

3.1 The Facility Layout Problem (FLP)

The layout planning problem can be categorized into different types, depending on the flow pattern and layout structure, as follows: (1) Single and Multi-row layouts, where departments are positioned in a straight line or in rows; (2) Cellular arrangements, according to Group Technology; (3) Unequal-area layouts where departments have different space requirements; and (4) Dynamic layouts where the decor is changed over several periods of time to suit the shifts in the environment. The main target functions generally are to reduce total material handling cost, which is determined by the flow volume between the departments and their distance from one another, to a minimum. Nevertheless, nowadays formulations frequently encompass diverse objectives e.g., scoring of proximity based on subjective traits, reduction of work-in-process, safety improvement, and increased flexibility.

3.2 Sources and Types of Uncertainty in FLP

Uncertainty in FLP arises from various sources, which can be broadly grouped into:

- **External Uncertainty:** Fluctuations in product demand, changes in product mix, and introduction of new products.
- **Internal Uncertainty:** Variability in processing times, machine breakdowns, and unreliable material handling systems.
- **Strategic/Qualitative Uncertainty:** Judgments that are not exact or are subjective with respect to closeness relations among the different departments (for instance, "A being close to B is very important"). Such uncertainty very often relies on language, and it is not easy to represent it in terms of probabilities.

Neglecting to consider these uncertainties might result in layouts that look perfect on paper but inefficiently perform in reality, which means either expensive reconfigurations or long-lasting inefficiencies.

4. Analysis of Solution Methodologies

The review of the 163 articles indicates a distinct ranking regarding the occurrence and usage of the solution methodologies. The main methodologies and their distribution are presented in Table 1.

Table 1
Prevalence of Primary Solution Methodologies in FLP Research

Method Category	Percentage of Articles	Key Specific Methods Mentioned
Heuristics & Metaheuristics	~75%	Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Simulated Annealing (SA), Ant Colony Optimization (ACO), Bee Colony Optimization.
Mathematical Programming	~25%	
- Exact Methods (Linear, Integer, Mixed-Integer)	~8%	Mixed-Integer Programming (MIP), Integer Programming, Linear Programming.
- Other/Applied in Hybrid	~17%	Stochastic Programming, Bi-level Programming.
Simulation	~20%	Discrete-Event Simulation, Agent-Based Simulation, Hybrid Simulation.
Multi-Criteria Decision Making (MCDM)	~30%	Fuzzy AHP, TOPSIS, DEA, VIKOR.

4.1 Mathematical Programming and Exact Methods

Mathematical programming formulations, like Integer Programming (IP) and Mixed-Integer Programming (MIP), create a strict framework for Facility Layout Problems (FLP). They ensure the best solution for the problem that was modeled. For instance, Kouvelis et al. (1992) were the first to illustrate the robustness of mathematical programming through the optimization models for both single and multiple period layouts. These models are very useful for tackling small to medium-sized problems or as a part of larger ones. Nevertheless, only around 8% of the literature reviewed, as indicated in Table 1, makes use of pure exact methods. This limited use is mainly due to the fact that FLP is NP-hard. The larger the problem (more departments), the longer the computational time for exact methods, and thus, it becomes impractical. As a result, their use is often limited to some specific, simplified cases of the FLP or to checking the performance of heuristic algorithms on small benchmark instances.

4.2 Heuristics and Metaheuristics

Metaheuristics are the most favored and preferred technique that is used in around 75% of the studies that were investigated (Table 1). The main reason behind this is their extensive flexibility along with their strong search prowess which makes them very apt for the complex, non-linear, and multi-modal search spaces of practical FLP problems.

- **Genetic Algorithms (GAs)** are recognized as the most frequently applying metaheuristic. They perform by the gradual improvement of a population of candidate layouts (chromosomes) through the operations of selection, crossover, and mutation. Ye and Zhou (2005) made SLP more effective with the help of a GA, while Lam and others (2005) associated the use of GAs with an entropy technique for site layout of construction. The main reasons for the popularity of GAs are their strength and capacity to deal with more than one goal at the same time.

- **Particle Swarm Optimization (PSO)** is one more very famous algorithm, which is modeled on the social activity of birds flocking. Xu and Li (2012) introduced a multi-objective PSO for dynamic construction site layout under a fuzzy random environment, proving its efficiency for intricate uncertainty. PSO has always been associated with quick convergence and straightforward implementation.

- **Simulated Annealing (SA)** is a technique that imitates the process of annealing in metallurgy. Choi et al. (2017) applied the combination of a GA and a Stochastic Growth Algorithm for the layout of the shipyard facilities optimal and at the same time, relying on SA for local refining. SA is a method capable of getting out of local optima but is also dependent on the proper setting of the parameters.
- **Ant Colony Optimization (ACO)** imitates the foraging habits of ants. The works of Ning et al. (2011) and Lam et al. (2007) made good use of ACO and a Pareto-based ACO, respectively, in the area of construction site layout problems successively because of its ability to deal with complex constraints and multi-objective optimization.

The usage of metaheuristics points out a major trend: researchers are no longer interested in proving the optimality of a solution but rather are aiming at finding the best solutions which are, at the same time, feasible and robust for realistic problems in a quick manner.

4.3 Simulation-Based Approaches

Simulation is employed in nearly 1/5th of the total papers (see Table 1), mostly in the form of a hybrid "simulation-optimization" framework. Discrete-event sim-ulation and Agent-Based Simulation (ABS) are extremely useful in determining the performance of a layout that is subject to varying and random conditions. On the contrary to analytic models, simulation has the ability to represent the complex, emergent behaviors of a system.

- **Evaluation:** Simulation can provide reliable estimations of performance indicators such as throughput, resource utilization, and work-in-process levels for an intended layout even taking into account stochastic events like machines breakdowns.
- **Optimization:** In the context of simulation-optimization approaches, a metaheuristic is steering the search towards promising layouts, and simulation is implementing the evaluation of each candidate layout. Razavialavi and AbouRizk (2017) came up with the GA-simulation framework for construction site layout planning. Besides, Barth et al. (2024) have relied on optimization and agent-based simulation for the planning of emergency exit layout.
- **Analysis of Uncertainty:** Using Monte Carlo techniques, simulation models can simply be viewed as a way to describe the landscape of uncertainty, where all the input parameters are treated as probability distributions.

Simulation use is expected to increase along with Digital Twins' their, which are the virtual counterparts of the real systems. Wang et al. (2024) showed a twin-digital approach to 3D layout optimization in reconfigurable manufacturing systems, thus marking a considerable step forward in simulation-based FLP.

5. Modeling Uncertainty in FLP

The analysis we have conducted indicates that more than 75% of the publications have incorporated uncertainty modeling into their research, with fuzzy logic being the most preferred technique. The various approaches to dealing with uncertainty are presented in Table 2.

Table 2
Methods for Handling Uncertainty in FLP Research

Type of Uncertainty	% of Articles	Description & Common Applications
Fuzzy Logic / Fuzzy Sets	**~45%**	Handling qualitative, linguistic uncertainty (e.g., closeness ratings), imprecise demands, and subjective judgments in MCDM.
Stochastic / Probabilistic	**~20%**	Addressing uncertainty with probability distributions (e.g., product demand, processing times). Uses scenarios, Monte Carlo simulation.
Robust Optimization	**~8%**	Finding solutions that perform well under a set of possible future scenarios, minimizing worst-case performance.
Fuzzy Random	**~5%**	A hybrid approach for when both stochastic and fuzzy uncertainties are present simultaneously.
No Explicit Uncertainty	**~22%**	Papers focusing on deterministic models.

5.1 Fuzzy Set Theory

In ~45% of the literature (Table 2), fuzzy set theory which was introduced by Zadeh and is significantly positioned for FLP because it can represent the qualitative and linguistic judgments which are the very core of the layout design process. The "closeness rating" between departments that is usually given in terms of "Absolutely Necessary," "Important," or "Unimportant" is fundamentally fuzzy.

- **Fuzzy Closeness Ratings:** Dweiri and Meier issued this paper in 1996 and were the pioneers in applying fuzzy decision-making to the planning of facilities layout in a systematic way, which involved turning linguistic proximity evaluations into fuzzy numbers. This method has become a norm ever since.
- **Fuzzy Objectives and Constraints:** "Flexibility," "safety," and "aesthetics" are aspects that can be treated as fuzzy goals. The work of Lin et al. (2015) is a notable example where SLP together with fuzzy constraint theory was

applied for the designing and optimizing of the operating theatre layouts, considering restrictive factors such as noise, privacy, and workflow as soft and subjective.

- **Fuzzy Demand and Parameters:** In situations where the upcoming demand cannot be clearly stated as an exact quantity, it is possible to depict it by a fuzzy number (e.g., "demand is about 100 units"). Zha et al. (2020) applied a hybrid PSO and SA technique to deal with the unequal-sized dynamic facility layout problems subjected to fuzzy random demands.

Fuzzy logic is very strong when it comes to its naturalness for human reasoning and thus, it supports the whole expert knowledge incorporation process in layout planning.

5.2 Stochastic and Probabilistic Models

Stochastic models, which account for about 20% of the papers (Table 2), are the methods of choice when there is historical data that can be used to determine the probability distributions of uncertain parameters. The most prevalent methods are:

- **Scenario-Based Planning:** A future consists of several possible scenarios, each of them coming with a certain probability. The goal is frequently to minimize the total expected cost for all scenarios (dynamic facility layout problem).
- **Stochastic Programming:** This pertains to the optimization of an objective function which incorporates random variables. To illustrate, Paul & Rather (2019) adopted a bi-level planning method combined with sequential Monte Carlo simulation to determine the economical and dependable arrangement of large wind farms, considering wind speed as a stochastic variable.
- **Queuing Theory:** Stochastic arrivals and service times have been modeled in systems where material flow and waiting times are influenced by the layout. Queuing theory was adopted by Duan et al. (2021) as a means to assess the performance of Robotic Mobile Fulfillment Systems with dynamic arrivals.

5.3 Robust Optimization

Robust optimization, present in approximately 8% of papers (Table 2), is a conservative strategy that results in the worst-case scenario being the only one considered. It aims to find solutions that are still viable and, at the same time, close to the best for the whole or most cases of the uncertain data within a certain uncertainty area. The main aim is to protect oneself against the worst situation. Kouvelis et al. (1992) in their pioneering study gave the basis for reliable layout planning and this method still applies in very unstable surroundings where the price of a wrong decision is enormous.

5.4 Hybrid Uncertainty Models: Fuzzy-Random

There are situations in complex environments where stochastic uncertainty and fuzzy uncertainty are present at the same time. For instance, demand for a product could be considered a random variable, but still, the mean or variance is determined through imprecise estimation (a fuzzy number). The concept of the fuzzy-random variable is a sophisticated means to represent this duality. Xu & Li (2012) were the first to apply this concept to the dynamic layout of construction sites, and they created a multi-objective model in which demands were represented as fuzzy random variables.

6. The Role of Multi-Criteria Decision Making (MCDM)

Indeed, the FLP is a multi-criteria problem by nature. Cost of material handling is a key factor and it is given the greatest weight, but safety, flexibility, ergonomics, and noise will never be removed from the list of concerns of the decision-makers. Our study suggests that around thirty-nine per cent of the reviewed papers have applied different formal MCDM techniques to choose the final layout from a group of alternatives produced by an optimization method. Table 3 illustrates the distribution of employed MCDM methods.

Table 3
Prevalence of MCDM Methods in FLP Research

MCDM Method	% of Articles	Description
Fuzzy AHP / FAHP	**~12%**	Combines AHP with fuzzy logic to handle imprecision in pairwise comparisons for weighting criteria.
TOPSIS / Fuzzy TOPSIS	**~10%**	Ranks alternatives by their distance from positive and negative ideal solutions.
AHP (Crisp)	**~5%**	Structures the decision problem in a hierarchy for criteria weighting.
Others (DEA, VIKOR, ELECTRE)	**~3%**	Data Envelopment Analysis (DEA), VIKOR, ELECTRE are used less frequently.

- **Fuzzy Analytic Hierarchy Process (FAHP):** The AHP is the most widely used MCDM method, with a participation rate of approximately 12%. FAHP, by combining AHP and fuzzy logic, takes care of the uncertainty in pairwise comparisons. Thus, Sharma & Singhal (2017) applied fuzzy TOPSIS to make the selection of the best procedural approach for FLP, whereas Rodriguez & de Oliveira (2022) proliferated SLP by the integration of fuzzy AHP and fuzzy VIKOR.
- **Technique for Order Preference by Similarity to Ideal Solution (TOPSIS):** Crisp and fuzzy TOPSIS (~10%) are the ones to go with for final layout selection. The ranking of the alternatives is done based on their closeness to the positive ideal solution and the negative ideal solution. Agarwal and Singholi (2018) also compared AHP-TOPSIS with FAHP-FTOPSIS for selecting FLP.
- **Integrated Approaches:** One of the major applications that have gained the most power in MCDM is the integration between involved methods. The paper by Ertay et al. (2006) is credited for introducing a groundbreaking framework that proposes the use of both the Analytical Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) for the purpose of evaluating layout alternatives, thus, qualitatively and quantitatively, they have effectively mixed the two factors together.

The application of MCDM is a sign of the field's maturity, which has shifted from focusing on the single objective of minimizing cost to a more holistic perspective on layout performance that is compatible with larger business and sustainability objectives.

7. Bibliometric Analysis and Research Trends

7.1 Geographical and Institutional Contributions

The spotlight of the analysis is on the global distribution of research output that is very clear. China is at the forefront of the researches, with a share of around 35% of the whole output. The schools such as Tsinghua University, Sichuan University, and Nanjing University of Aeronautics and Astronautics are the most active in the industry and they concentrate mainly on the application of their findings in the building, power and manufacturing sectors. Next to China is the USA with a portfolio of contributions covering a wide range of areas like strong optimization, simulation, and AI-based methods. India is the country where the application of fuzzy MCDM and metaheuristics to manufacturing optimization is making a great impact and the growth is mainly ascribed to that. On the other hand, Turkey and Iran are countries with active research communities that in general prefer working on fuzzy logic and hybrid metaheuristics. Among the European countries, particularly Germany is known for its high-quality research in the fields of reconfigurable manufacturing, swarm production, and digital twin integration. The distribution of the leading countries in terms of publications is given in Table 4.

Table 4
Top Contributing Countries to FLP under Uncertainty Research

Country	Number of Publications	Key Contributing Institutions
China	**~35%**	Tsinghua University, Sichuan University, Nanjing University of Aeronautics and Astronautics.
USA	**~12%**	University of Arizona, Penn State University, University of Michigan.
India	**~10%**	National Institute of Technology (multiple), Lovely Professional University.
Turkey	**~8%**	Istanbul Technical University, Yildiz Technical University.
Iran	**~7%**	Amirkabir University of Technology, University of Tehran.
Germany	**~5%**	Otto-von-Guericke-Universität Magdeburg, Karlsruhe Institute of Technology.

7.2 Influential Authors and Papers

The most prominent researchers in the respective area can be recognized the best through the analysis of citation counts of their published papers as it is clear from Table 5. Citations are a consistent measure of the influence and significance of the research work, indicating how much a particular study has been responsible for later research. Among the remarkable contributions, the combination of the Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA) by Ertay et al. (2006) can be regarded as one of the basic breakthroughs in the use of Multi-Criteria Decision Making (MCDM) methods for Facility Layout Problems (FLP). The marriage of these two methodologies has created a solid base for the assessment of complicated decision-making situations involving many opposing criteria. The works of Xu and Li (2012) are equally important as they put forward models that covered fuzzy-random environments, thus making decision-tools under uncertainty more real-world-oriented and applicable. Ning et al. (2011) also reached important new areas by constructing decision-support systems that were specifically made for construction management, thus providing practical solutions for the industry's challenges. Furthermore, the early research of Dweiri and Meier (1996) on fuzzy decision-making has won them citations even after many years, as they are recognized for their significant role in the development of uncertainty modeling. Likewise, Kouvelis et al. (1992) shared their critical view on robust optimization, which is still a key area of research in operations and mainly in strategic planning. The continued, let alone, acknowledgment of these pioneering works signifies their indispensable part in the transition from the past to present-day and preparing the way for future innovations in decision-making science.

The references of Xu and Li (2012) have equal importance since they presented models for dealing with fuzzy-random environments, thus making the decision-making tools under uncertainty more realistic and applicable. The researchers Ning et al. (2011) also presented new paths by means of construction management based decision-support systems which provided practical solutions to the specific challenges of the industry. Moreover, the initial work of Dweiri and Meier (1996) in fuzzy decision-making continues to be widely cited, thus indicating the long-lasting impact they have had on the development of uncertainty modeling. Likewise, Kouvelis et al. (1992) brought to the table very important knowledge in robust optimization, which is still the case in operations research and strategic planning. The constant importance of these original studies in the development of the contemporary approaches as well as the future innovations in decision science has been highlighted by their indispensable role.

Table 5
Selection of Highly Cited and Influential Papers

Authors (Year)	Title	Cited By	Key Focus
Ertay, Ruan, & Tuzkaya (2006)	Integrating data envelopment analysis and analytic hierarchy for the facility layout design in manufacturing systems	225	MCDM, DEA, AHP
Xu & Li (2012)	Multi-objective dynamic construction site layout planning in fuzzy random environment	117	Dynamic layout, Fuzzy Random, MOPSO
Ning, Lam, & Lam (2011)	A decision-making system for construction site layout planning	121	Decision Support System, ACO, Intuitionistic Fuzzy
Kouvelis, Kurawarwala, & Gutiérrez (1992)	Algorithms for robust single and multiple period layout planning for manufacturing systems	173	Robust Optimization, foundational work
Dweiri & Meier (1996)	Application of fuzzy decision-making in facilities layout planning	90	Early Fuzzy MCDM application
Lam, Tang, & Lee (2005)	Application of the entropy technique and genetic algorithms to construction site layout planning...	40	GA, Entropy, Construction
Karray et al. (2000)	Tools of soft computing as applied to the problem of facilities layout planning	39	Soft Computing (Fuzzy, GA, Neural)

7.3 Evolution of Application Domains

The application of FLP under uncertainty has expanded far beyond traditional manufacturing floors.

- **Construction Site Layout Planning (CSLP):** This sub-field is significant and its dynamic trait is a major characteristic. Throughout the project's phases, temporary facilities (offices, warehouses) have to change their locations. Elbeltagi & Hegazy (2001), Lam et al. (2005), and many more have contributed highly complicated dynamic models for this area.
- **Logistics and Supply Chain:** Layout planning is still an active field of research when it comes to warehouses, logistics parks, and container terminals. He and Xue (2009) made use of fuzzy clustering for the arrangement of logistics parks, whereas Golbabaei et al. (2012) deployed the AHP method for the assessment of stacking yard configurations in container terminals.
- **Energy Sector:** The global transition to renewable energy has led to the discovery of new uses for FLP in the redesign of wind farms (Lerch et al., 2021; Paul & Rather, 2019), locations for hydrogen refueling stations (Wang et al., 2024), and setups for electric vehicle charging networks (Yang et al., 2025; Zhang et al., 2023).
- **Healthcare and Services:** One of the emerging areas is the use of better layout design to improve efficiency in hospitals. The application of FLP methods to operating rooms by Lin et al. (2015) and to diabetes clinics by Mishra (2024) has been on the patient safety and the staff workflow improvement, respectively.

8. Research Gaps and Future Directions

Despite significant advances, several challenges remain and present opportunities for future research:

1. **Real-Time Dynamic Layout Reconfiguration:** The majority of the dynamic models consider reconfiguration at fixed intervals. The subsequent investigation may deal with the continuous, adaptable layout management based on the information collected from IoT sensors and AI, wherein the layout is capable of self-adjustment during breakdowns or sudden increases in order volume.
2. **Integration of AI and Large Language Models (LLMs):** The very recent research of Qian & Shi (2025) with their LLM-based automated geotechnical site planning already indicates a revolutionary way preparing the site without the help of an LLM. The application of the LLMs might be to decode the underground design documents, get the proximity relationships from the free-flowing text, and even outline the preliminary plans.
3. **Human-Centric and Ergonomic Layouts:** The influence of people is often treated as a less complex issue in the multi-criteria decision-making process. It is recommended that the next-generation models take into account the proper ergonomic design, cognitive load, and human-robot collaboration safety to be interconnected in the layout optimization cycle.

4. **Sustainability and Resilience:** The explicit optimization of layouts for carbon footprints (e.g., Geng et al., 2023) and energy consumption is now a necessity. Moreover, the creation of layouts that can withstand significant disturbances (e.g., pandemics, supply chain disruptions) is a major challenge of the future.
5. **Standardized Benchmarking and Explainability:** The field is missing standardized benchmark problems for FLP concerning complex and hybrid uncertainties. In addition, as models become more complex (e.g., deep reinforcement learning), it will be necessary to create methods that can explain and interpret the AI's layout recommendations in order to win the trust of practitioners.

9. Conclusion

This extensive review is providing a synthesized summary of the present research terrain in Facility Layout Planning (FLP) under uncertainty, gathering insights from a meticulous single analysis of 163 academic papers. The area is predominantly ruled by metaheuristic algorithms, with Genetic Algorithms and Particle Swarm Optimization being the most frequently used solution methods. The reason for their widespread usage is the very nature of FLP being NP-hard which makes it necessary to use strong and flexible optimization techniques that will be able to operate through the intricate decision spaces.

Fuzzy set theory has gradually advanced to become the primary modeling paradigm in dealing with layout design uncertainty. It does so by providing a comprehensive representation of the uncertain, sometimes even vague, and qualitative inputs which constitute the planning process in real-world situations. The combining of fuzzy logic with MCDM techniques—in particular, the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) and the Fuzzy Technique for Order Preference by Similarity to Ideal Solution (Fuzzy TOPSIS)—has become a normal way of assessing layout options along several different and often opposing criteria. The bibliometric study indicates the presence of a lively and internationally dispersed research community, with China being the most active country in terms of publications and innovations. The main areas of application are the management of construction sites, the design of sustainable logistics networks, and the development of energy infrastructure systems. The theme is still very much alive and is rapidly changing the landscape of layout planning through the adoption of the latest technologies such as Digital Twins, Large Language Models, and sophisticated AI, which will facilitate communication, and make planning processes more adaptive and user-friendly. The transition from deterministic and cost-focused models to dynamic and uncertainty-aware frameworks mirrors the increasing complexity of industrial and service systems. Integration, explainability, and autonomy will be the major factors driving the future development of decision-support systems.

A bibliometric study of the literature has indicated that the research community is not only highly active but also well spread around the globe, with China at the forefront in terms of both the number of papers and the innovation stemming from them. The leading application domains are the dynamic construction environments, sustainable logistics networks, and energy infrastructure systems. The industry is still changing quite fast, and new technological developments, like Digital Twins, Large Language Models, and advanced AI, are setting the path towards more adaptive, intelligent, and human-centric solutions for layout planning. The transition from deterministic, cost-oriented models to dynamic, uncertainty-aware ones mirrors the increasing complexity of industrial and service systems. It is expected that the future will bring major advances in the areas of integration, explainability, and autonomy in decision-support systems.

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