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Layout optimization methods and tools: A systematic literature review

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RESUMO

Objetivo: Este artigo tem como objetivo apresentar os métodos e ferramentas de otimização de leiaute que vem sendo empregadas desde 2010 nos mais diversos ambientes produtivos.
Referencial Teórico: Devido à intensa competitividade e incertezas do mercado atual, aprimorar processos e aumentar a eficiência da produção por meio do gerenciamento de um leiaute de instalações pode ser uma das formas de trazer benefícios às organizações. Nesse contexto, conhecer as principais ferramentas e métodos é essencial para definir a condução do seu estudo.
Desenho/metodologia/abordagem: A pesquisa foi realizada por meio de uma revisão sistemática da literatura. As bases de dados utilizadas foram Science Direct e Portal Capes. Por meio de palavras-chave do escopo definido e da relevância do tema, os artigos internacionais foram selecionados para leitura e discussão.
Resultados: Por meio da revisão foi possível selecionar 51 artigos considerando sua relevância para o tema. Devido à complexidade do estudo de gerenciamento de leiaute, descobriu-se que cada vez mais algoritmos, modelos matemáticos e computacionais estão sendo usados para resolver esses problemas NP-difíceis.
Implicações de pesquisa, práticas e sociais: habituar-se a novos métodos e maneiras de resolver problemas de leiaute de instalações, embora possam ser nos mais diversos cenários, pode melhorar os resultados de negócios tornando o processo mais eficiente.
Originalidade / valor: O artigo compila e explica resumidamente os métodos encontrados para a otimização do leiaute, o que é de grande importância tendo em vista que o conhecimento desses modelos dissemina práticas de gestão produtiva.
Palavras-chave: Otimização de leiaute. Algoritmo. Método. Planejamento de layout de instalações.

ABSTRACT

Purpose*: This article aims to show the methods used to optimize layout and tools that have been applied since 2010 in the most diverse production environments.*
Theoretical Reference*: Due to the intense competitiveness and uncertainties in the current market, improving processes and increasing production efficiency by managing the layout of a facility can be one of the methods to benefit organizations. In this context, knowledge of the main tools and methods is essential in defining the conduct of studies.*
Design/methodology/approach*: Research was carried out through a systematic literature review. The databases used were Science Direct and Portal Capes. Using keywords, a defined scope and the relevance of the theme, international articles were selected for reading and discussion.*
Findings*: Through the review, it was possible to select 51 articles which were relevant to the topic. Due to the complexity of the layout management study, it was found that increasingly more algorithms, mathematical and computational models are being used to solve these NP-hardness problems.*
Research, Practical & Social implications*: adjusting to new methods and ways of solving problems laying out facilities, although scenarios can be extremely varied, they can improve business results by making the process more efficient.*
Originality/value*: The article compiles and briefly explains the methods found to optimize the layout, which is of great importance considering the knowledge that these models spread on production management practices.*
Keywords*: Layout optimization. Algorithm. Method. Facility layout planning*

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1. INTRODUCTION

The layout of industrial facilities, the location of equipment, machinery and even the layout of furniture in professional environments are one of the fundamental aspects that directly interfere in the productivity and possible companies' success. According to Carlo *et al.* (2013), competitiveness requires professionals to constantly improve manufacturing practices and logistics. Within this search for improvement opportunities, the layout is an integral part of the manufacturing and has a relevant impact on costs and minimization of distances to the operational efficiency (SILVA *et al.*, 2012). Based on Canen and Williamon (1998), "the best movement of the material is not to move".

Tompkins *et al.* (2010) found that an ineffective layout design and material handling represents between 20% and 50% of the total production costs. It's estimated the problem of placing departments that achieve an optimal solution reduces handling and operational costs about 10%-30% and increase the production efficiency by removing unnecessary processes. Errors in layout design can generate interruptions in supply, leading to internal and external consumer dissatisfaction, production delays, causing confusing and unnecessary queues and stocks, in addition to high costs related to inefficiency in creating synergy between the physical arrangement set (KANNAN, 2010; SINGH; YILMA, 2013).

Manufacturing companies are redesigning their production systems to address new production technologies or product changes, which require a comprehensive planning process to form the final design changes (SCHUH *et al.*, 2011). It is supposed a good layout design gives companies better use and organization of available space and in the internal flow of people and machines, facilities in the supervision of tasks and material handling, reduction of time and stock between processes, and lower operating costs.

Taking into account these advantages, the methods and tools of layout management are the study object of this article, which aims to understand the scenario and the principles that guide it. Therefore, the purpose of this work is, through a systematic review of the literature, examine that one's applied and studied in the last 10 years in manufacturing companies. Although the results are quite restricted to unequal area and single row layout cases, the practical use of these features is likely to become even more common in future, comprising over time a greater diversity of situations. The benefits of achieving a more optimized process explain the importance of this review.

The article sequence is organized as follows: section 2 presents a brief theoretical referential on the subject; in section 3, the materials and methods used for research are detailed, as well as the definition of databases and keywords, the creation of the article collection and selection protocol and a result overview; in section 4, a quantitative analysis of the results takes place; section 5 succeeds a more in-depth discussion about optimization methods and tools, explaining the most frequent, it's particularities and how they were tested and applied; in section 6, finally, the conclusions regarding the research are described.

2. THEORETICAL FOUNDATION

According to Slack *et. al*. (2018), a physical arrangement is one of the most evident characteristics of a productive operation, because it determines the shape and appearance of its environments. It is possible to visually perceive some problems in the layout of associations, such as the crossing of flows or excessive movement, but in order to propose an improvement in the layout of a productive arrangement, it is necessary to follow a methodology, using tools for this purpose. (SLACK *et al*., 2018).

The main layout rearrangement method is SLP - Systematic Layout Planning, combined with improvement tools related to the process, products and ergonomic aspects of the productive system. The second most used method consists only of the use of analysis tools for the definition of the new layout. (NEGRÃO *et al*., 2019). However, the application of conventional optimization methods to modern production lines is not only becoming too complex, but also becoming inaccurate and unreliable (HO *et al*., 2019), decreasing the quality that could be achieved using some more advanced method.

Improving the architectural layout for diverse objectives using rigorous mathematical optimization methods gradually receives more attention by the researchers (ZAWIDZKI; SZKLARSKI, 2020), trying to result in more optimized, accurate and effective technique. Among the most used methods, the following stand out: Heuristic methods such as genetic algorithms, coral reef, ant colony, particle swarm optimizations and local search strategies. In addition to these, according to the same authors, more recently, to deal with the qualitative aspects of the manufacturing environment, they are being used, among others: implementation simulated annealing has been documented in, tabu search, biased random-key genetic algorithm and mixed integer linear programming.

The development of the modern industry has poses new challenges for facility layout planning (JIAN; NEE, 2013). To meet the fast-changing production targets, enterprises nowadays need to reconfigure the existing shopfloor layouts constantly to update their operations. Therefore, in addition to algorithm tools, virtual reality has also been widely used. By creating a 3D virtual environment, the VR-based tools allow the users to design layout plans manually based on their knowledge and experience (JIAN; NEE, 2013).

3. METHODOLOGICAL PROCEDURES

The integral development of the research and consequent studies were carried out in accordance with the approach known as systematic literature review (SLR). SLRs offer readers comprehensive knowledge of the literature in a field through a holistic and organized précis that adheres to standard protocols (AFROOZ; NAVIMIPOUR, 2017; AHMAD *et al.*, 2018; MEHTA; PANDIT, 2018).

The progress of the study, which aims to exhibit the qualitative and quantitative panorama of the methods and tools for layout optimization, was divided into three main stages explained below, following the approach developed by Kitchenham *et al.* (2009). First, the research questions must be defined. Then, the protocol development must be started, reducing the possibilities of biases through search arguments. Selection criteria and quality filters must be described before starting data extraction. The steps are described below:

- Review planning: where the theme and the collection protocols that would be used were defined, with identification of the need for a review.
- Conducting the research: with clarification of the parameters used for the selection and evaluation of articles, data extraction and data syntheses.
- Dissemination and reports, when the content is reviewed and the study bibliometrics occurs.

3.1 Definition of databases and keywords

In this stage, the main Brazilian portal, the periodical CAPES, and the international platform Science Direct were chosen as the main databases for searching relevant articles. Gathering academic and scientific works in their collections that cover vast areas of knowledge, the platforms were selected and used for the quality of the works that went through a rigorous filtering process before being published. Besides that, most of the articles found were also inserted in other portals, however, CAPES and Science Direct were already known. This familiarity and fluency of the Portuguese language by the authors, in CAPES case, facilitated their use. In addition, the authors had free access to all the content available on the channels, since the entry on the sites was made through the Internet Protocol Address of Federal University of Paraná, which allowed access to the platform's signed content for being part of the participating institutions.

Subsequently, the search keywords that would achieve an adequate result according to the objective of the study were defined. Within the scope of search strings, the conjunction "OR" suggested the possibility of a synonym also find good results and the conjunction "AND" was used to combine two groups of words. The first one varied between "Layout", "Layout Rearrangement", "Layout Project", "Layout Reformulation", "Layout Design", "Layout Planning", "Physical Arrangement", "Layout Optimization", "Unequal Area Facility Layout Problem", "Layout Solving", "Plant Layout Study" until reaching the most accurate result defined as "Layout (Optimization OR Planning OR Solving)". The second started with "Methodology OR Method OR Mechanism OR Tool" and ended in "Novel (Tool OR Method OR Methodology)".

3.2 Creation of the article collection and selection protocol

In a second step, through the dynamic reading of the articles, those that were relevant to the purpose of the work were selected. It should be noted that filters were applied to make the studies feasible. Among them, only articles published between the years 2010 and 2020, in journals classified as A1, A2, B1, B2 or B3 according to the Sucupira platform would be selected. The platform makes available on its channel the evaluation and recognition of journals according to some criteria applied to Engineering III topic, where industrial engineering is located. The indexing of journals in the database InCites Journal Citation Reports (JCR) and Scopus, the national or international coverage of the works, scientific or not, and well-defined editorial policies are criteria used for classification. Besides that, results of the search were sorted for "relevance" before reviewing abstracts, due to the length of the search string, including articles from multiple disciplines, such as Engineering, Energy, Sustainability, Aerospace Science, Architecture and others.

The number of results was quite high, so, when the articles stopped making sense in relation to the searched topic, the searches were stopped. In Science Direct database, which offered the possibility of applying another filter to the title, abstract and keywords, the set “Layout AND Optimization AND (Tool OR Method)” was also used. After that, the snowball method was applied to the references of the selected articles, aiming to include the relevant ones that could have been excluded from the selection during the research. Obtaining new articles through references cited by the authors created a loop and stopped only when articles applied to the theme were no longer identified. The same filters mentioned above (date and Sucupira classification) were used. The selected articles were organized in an Excel spreadsheet.

After finishing all the process mentioned above, a new search for articles published in 2021 occurred, to guarantee the presentation of the latest state of the art articles considering the same conditions as applied before. They were not counted in the quantitative analyses, and their contents were only addressed in the qualitative part.

3.3 Results overview

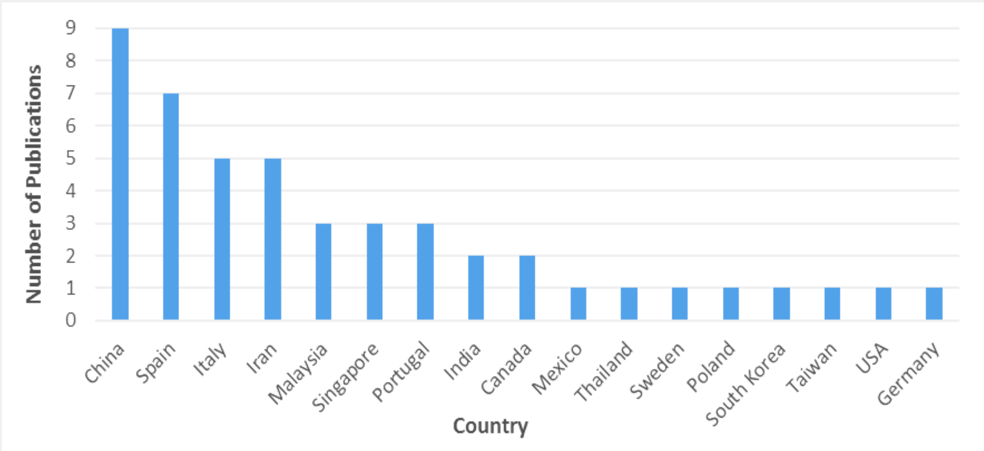
The previously selected keywords combination, “Layout (Optimization OR Planning OR Solving) AND Novel (Tool OR Method OR Methodology)”, which triggered relevant results to the research objective, was inserted in two databases: Science Direct and Periodical CAPES. According to the systematic literature review methodology, the keywords, without applying filters, resulted in 36621 articles found in Science Direct and 24930 in CAPES. From the moment the date (2010-2020) and classification filters were applied according to the Sucupira platform (A1, A2, B1, B2, B3), the results were reduced in CAPES to 18541 studies. In Science Direct, in addition to these filters, the keyword “Layout AND Optimization AND (Tool OR Method)” was applied to the title, summary and keywords of the articles, reaching 437 works. Of the total of 18978 articles, 44 articles were selected through dynamic reading, of which 17 were excluded either because they were repeated or because they were not classified on the Sucupira platform. Added to the remaining 27, 20 articles were found by

Snowball Sampling, resulting in a sample of 47 reviewed articles for the construction of this study. Besides that, 4 articles from 2021 had their contents studied.

4. RESULTS

Analyzing the quantitative results, the predominance of some countries in the research on methods and tools for layout optimization is notable. This is due to the fact that they belong to the countries that receive the most investments in research and development, have group studies focuses on the topic and, in the case of China, have large industrial and manufacturing parks. China stands out, with 9 articles published in this area, followed by Spain, with 7 works done (see fig.1). The dominance, if portrayed by continents, becomes even more evident, since Asia published 25 articles related to the theme, followed by Europe with 18 publications. America appears with only 4 works related to the subject.

Figure 1 - Publications by country.

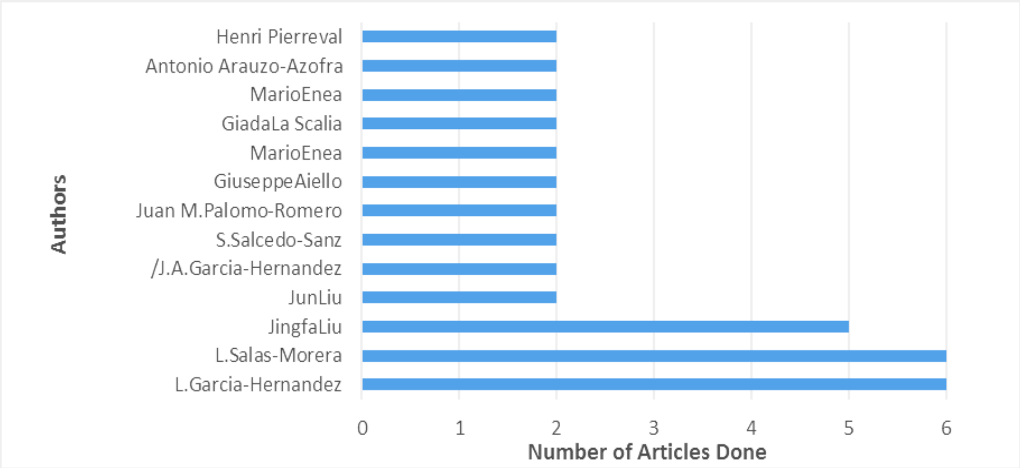


Note: Country reflects the location of the institute to which the first author is affiliated.

Following the same patterns mentioned above, regarding the understanding of the research status, traced through the review of the articles, the most frequent authors are also Spanish and Chinese. Among those who took part in more than one research in relation to layout optimization methods and tools, Laura García Hernández, who currently works at the Department of Rural Engineering doing researches in Computer Engineering, Engineering Education and Industrial Engineering and Lorenzo Salas-Morera, who works in the Area of

Project Engineering doing research in Interactive Evolutionary Algorithms and Educational Technology, from the University of Córdoba (Spain), are the most relevant. Jingfa Liu, from the School of Information Science and Technology (China), comes soon afterward in order of expressiveness (See figure 2).

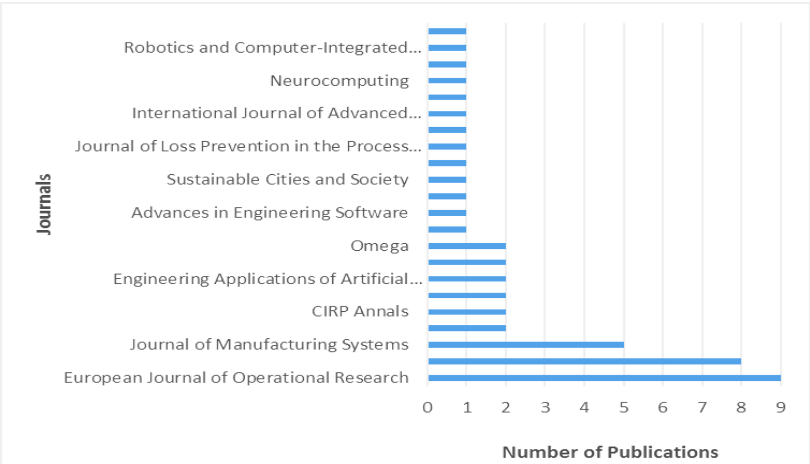
Figure 2 - Most Frequent Authors



Source: The authors.

The selected articles were published in several journals, however, the leading sources were European Journal of Operational Research (9 publications), followed by Expert Systems with Applications (8 publications) and, then, Journal of Manufacturing Systems (5 publications). (See figure 3)

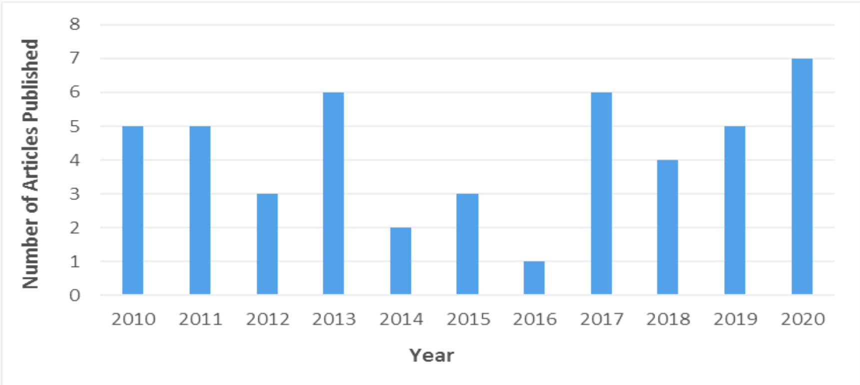
Figure 3 - Publications per Journal



Source: The authors.

Regarding to the years of publication of the selected articles, the last three years analyzed show a growth trend, signaling, perhaps, that research and new discoveries on the layout methods and tools subject will be among studies carried out in the coming years, due to such importance and influence in the context of company performance and the emergence of new technologies. (See figure 4)

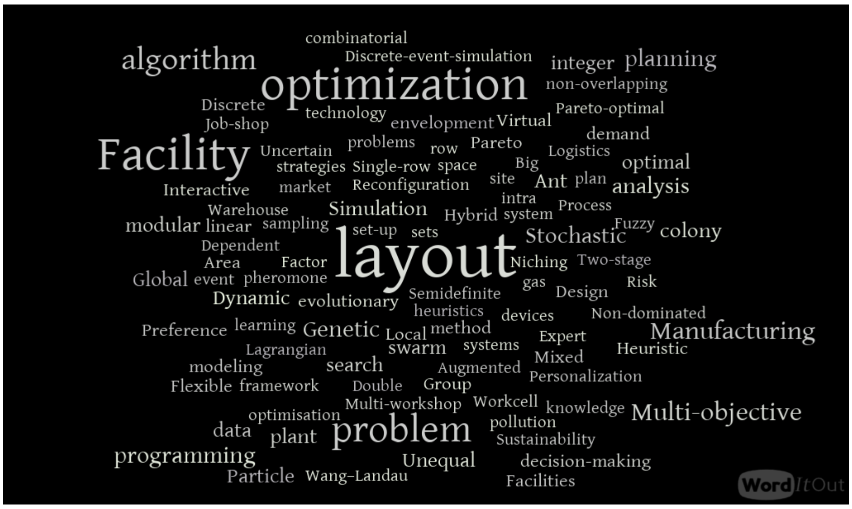
Figure 4 - Number of Articles Published by Years



Source: The authors.

Finally, to obtain an overview of the found results, the keywords detailed in each of the articles studied were gathered, for later construction of a word cloud that represents the main focuses of the research. An attractive arrangement of randomly positioned words were created by “Word it out” online software, where the most important and cited words are bigger than the others. It is perceived, through the directly proportional relationship between the size of the word and the number of times it was repeated, great emphasis on possible combinations that would result in Layout Optimization and Facility Problem. In addition, some words directly related to algorithms and mathematical models used to search for optimal solutions are identified, such as Genetic Algorithm, Ant Colony, Pareto-optimal, Simulation, Modeling, Augmented Reality, Multi Objective, and Particle Swarm Optimization. (See figure 5)

Figure 5 - Authors keywords



Source: The authors.

5. DISCUSSIONS

Through a systematic review of the scientific literature, 51 articles were selected for the study. Next, important concepts will be presented that permeated the studies and ensured that the works had the due reliability. A brief explanation of the main methods found will be carried out at the end, as well as possible directions and recommendations for future research in the area.

5.1 Research topic

The facility layout problem is the problem of placing facilities in a certain shop floor so that facilities do not overlap each other and are satisfied with some given objectives (LIU *et al.*, 2018). It is an NP-hard combinatorial optimization problem related to maximize the performance and minimize the operating, material handling and rearrangement costs. The conventional facility layout problem is concerned with arranging a number of interacting facilities, such as machines or departments (CHE *et al.*, 2017), being studied within three different contexts: single row (along one side of the path), double row (in two sides or two parallel rows of a central corridor or aisle) or multi-row (in some fixed numbers of rows). Most of the selected articles refer to the study of layout problems with single row and unequal areas.

5.2 Unequal area facility layout problem

Deal with the layout of departments in a facility, encompassing a class of extremely difficult and widely applicable multi-objective optimization problems with constraints arising in diverse areas and meeting the requirements for real-world applications (LIU *et al*., 2019). It is commonly encountered in industry practice, being a relevant task in manufacturing and is a hard optimization problem, in which traditional optimization techniques do not obtain good results (HERNANDEZ *et al*., 2020). Have been identified in the select articles, various kinds of heuristics and meta-heuristics to solve such problems over the past several decades. Most of them study either the quantitative single objective (material handling) or multi-objective Unequal Area Facility Layout Problems, which are usually converted into a single objective problem by using a weighted-sum method (LIU *et al.*, 2020).

5.3 Testing and application

The approaches used or identified by each author in studies that sought to find efficient solutions to layout problems were tested, most of the time, comparing results with state-of-art methods and benchmark problems in representative instances, performance metrics and hypothetical data of the literature or experimental studies in companies. In some cases, virtual manufacturing work cells were developed and utilized to evaluate the proposed methodology, even as computational experiments on a real-life or randomly generated instances. The methods were mainly implemented in manufacturing plants, but closely related research was conducted in construction sites, family houses and job shops.

5.4 Solution methods and tools

The articles show that there is no single best approach to solve the FLP. It needs to select a method according to the characteristics of the problem such as size, linearity, and non-linearity (MOSLEMIPOUR *et al.*, 2012). Because of that, some authors combine two or more algorithms that solve the same problem, looking for cluster desired features of each one and reconcile different combinatorial restrictions and objectives simultaneously. A better overall algorithm can be found by a Hybrid study. In addition, classic approaches are very slow or deviate considerably from optimal solutions. The development of heuristic techniques comes against that, aiming for faster and more accurate resolutions.

In this context, there is a high importance and relevance to the use of algorithms in order to rearrange and optimize layouts, since it corresponds to the vast majority of the works gathered. Besides that, several papers seek to achieve Pareto-optimal solutions, related to use a multi-objective constrained genetic algorithm that achieves the best result among those studied. In this case, there is no way to improve the value of any of its objective criteria without degrading the performance of other aspects of the model. Slicing Tree Representations or Structure were also widely used to easily represent the problems without restricting the solution space, dividing a facility in proportion to the areas of the departments.

Investigating the content of the selected articles, there is a considerable relevance of some methods compared to others less cited. Due to the frequency they are applied and studied in the literature conglomerate, each one with its respective particularities, these approaches will be discussed in greater detail below:

- Genetic Algorithm: is a stochastic search technique that mimics the mechanisms of the Darwinian evolution based on the concept of the survival of the fittest (GOLDBERG, 1989). The process starts with an initial random population of N individuals generated, named chromosomes. Iterations and operations evolve it successively, choosing the higher fitness chromosomes by evaluating. The crossover and mutation procedure combine two present chromosomes and try to improve a single one, respectively. The best fittest values survive as elite children. The usual process is repeated until a specified number of iterations is reached. There are several variants of genetic algorithms proposed, but, in general, they have the ability to combine with other algorithms and find the best solution for different kinds of layout problems. However, can be slow, the convergence is not guaranteed and depends on evaluation performance (MOSLEMIPOUR *et al.*, 2012). Juan M. Palomo-Romero *et al.* (2017) proposed an island model to solve problems such as premature convergence, lack of diversity, or high computational cost. Aiello et al. (2013) proposed a multi-objective and an electre method that optimized the several objective functions simultaneously and allows the decision maker to express his preferences on the basis of the knowledge of candidate solution set. Aiello *et al.* (2012) suggested a GA based upon the slicing structure where the relative locations of the facilities on the floor are represented by a location matrix encoded in two chromosomes. Gonçalves and Resende (2015) presents a biased random-key to determine the order, dimensions and strategy of placement, and a linear programming model. Caputo *et al*. (2015) used a genetic algorithm including pumping costs and safety issues. Hernandez et al. (2013) introduced expert knowledge to support the decision maker and adjust process qualitative preferences. Vitayasak *et al.* (2016) focused on a backtracking search algorithm to solve stochastic demand problems. Ning *et al.* (2019) proposed a hybrid genetic algorithm-ant colony optimization model to obtain trade-off solutions, reducing noise pollution by planning construction. Jiang and Nee (2013) adopted an Analytical Hierarchy Process–Genetic Algorithm for automatic layout planning. Datta *et al.* (2011) applied a permutation-based to arranging a number of facilities on a line with minimum cost.

- Coral Reef Optimization Algorithm: was recently proposed by Salcedo-Sanz *et al.* (2014) and imitates the evolution of coral reefs and the different processes occurring in these ecosystems (HERNANDEZ *et al*., 2019). Briefly, the process consists in: firstly, an initial population of the reef is randomly generated. Then, new solutions (larvae set) are created from the ones belonging to the reef in order to compete for a place in the reef. If the larva has a better health function value or the spot is empty, larvae present in the water settle in the reef. After that, a fraction of the corals with better fitness present in the reef duplicate themselves and are released to the water, trying to settle using the same conditions above. Finally, the worse evaluation fraction is depredated. Hernandez *et al*. (2020) proposed this method with substrate layers to solve the unequal area facility layout problem. According to her, it increased the diversity generation within the algorithm, which is helpful to improve the exploration of the searching space, avoiding to fall into local minima, consequently, finding better solutions with less computational cost. Hernandez *et al.* (2020) confirmed the excellent performance of the proposed algorithm in solving unequal-area facility layout problems.
- Ant System/Colony Optimization: is a bio-inspired optimization algorithm based on simulating the behavior of natural ants that succeed in finding the shortest paths from their nest to food sources by communicating via a collective memory that consists of

pheromone trails (LIU; LIU, 2019). Ant Colony Optimization algorithms have been used to find the shortest tour in the traveling salesman problem and needs to be converted into the problem of finding the shortest path on a weighted graph. Jingfa Liu and Jun Liu (2019), Wong and See (2010) and Komarudin and Wong (2010) applied the method and its variants to update the layouts and add the diversity of solutions. Moslemipour *et al.* (2012) declared the Ant Colony Optimization is robust and flexible in dynamic environments but it is not easy for coding and has disadvantage in parameters initializations by trial and errors or at random.

- Particle Swarm Optimization: works by having a population (called cloud or swarm) of individual candidate solutions (particles). These particles are moved around in the search-space according to a few simple formulae (ZHANG, Y., 2015). The standard Particle Swarm Optimization is very simple and easy to implement (MOSLEMIPOUR *et al*., 2012). The new location of each particle is determined by a velocity term, which reflects the attraction of global best and its own best during the history of the particle and random coefficients (SAHAB *et al*., 2013). When improved positions are being discovered these starts guiding the swarm flow. The process is repeated until the local best swarm and global leader particle are identified. The method, used by Samarghandi *et al.* (2010), Guan *et al.* (2019), Guan *et al.* (2020) and Liu *et al. (*2018) is fast, cheap and there are few parameters to adjust (MOSLEMIPOUR *et al*., 2012).
- Mixed integer linear programming: It is a mathematical optimization program in which the objective function and the constraints are linear and the variables are integers and continuous. Zhang *et al.* (2017) formulated the integrated optimization problem with the objective of minimizing the total cost of production and warehouse operations. Guan *et al*., (2019), used a mixed integer linear programming model with three objectives: minimization of overall material handling costs, minimization of number of workshops, and maximization of utilization ratio of workshop floor. Anjos and Vieira (2017) identified this approach as the main contributions to the facility layout problems area.

In addition to the approaches used above, other tools and solutions, identified with lesser degree of use within the scope of the selected articles, can be manipulated in order to help solving the problems of rearrangement and layout optimization. With the advent of new technologies tools, the use of realistic visualization, augmented reality, big data, machine learning and data envelopment tends to become increasingly common. Lindskog *et al.* (2017) show how to reduce the time required for planning and implementing the redesign by supporting the process with realistic visualization looking for analyze and evaluate planned changes prior to implementation. Nee *et al.* (2012) emphasize the importance of designing and providing intuitive and effective human interfaces, as well as suitable content development in order to make augmented reality a powerful tool in the manufacturing engineering field. Lee *et al.* (2011) constructed a computer-simulated mixed reality environment for virtual factory layout planning integrates real objects, such as real images, with the virtual objects of a virtual manufacturing system, minimizing the cost of implementing virtual objects and enhances the user's sense of reality. Manzini *et al.* (2018) integrated different computational tools addressing the design of the system, the optimization of the layout, the planning of reconfiguration actions as well as production planning.

Among the articles published in 2021, that represents the latest state of the art works found, it is worth mentioning 4 relevant studies that relate to the research topic. Cubukcuoglu *et al.* (2021) presents a heuristic optimization algorithm (Iterated Local Search) developed in a CAD environment for Quadratic Assignment Problem in a hospital context, as well as its implementation as a computational design tool. The tool calculates distances using graph traversal techniques, minimizing the internal transportation processes between interrelated facilities demonstrated in 3D. Chinnathai *et al.* (2021) proposed a novel Data-Driven Scale-up Model (DDSM) that builds upon kinematic and Discrete-Event Simulation (DES). It identifies a near-optimal configuration with a multi-objective Genetic Algorithm (GA) supporting decision-making activities, with significant savings in time, cost and effort in a manufacturing line. Ozden *et al.* (2021) present a computational software system using a meta-heuristic for facilitating the design of warehouse layouts to near-optimality, considering the average walking distance of the picker. Guo *et al.* (2021) put forward a method of flexible cellular manufacturing based on digital twin. It continuously optimizes the method, based on decoupling event mechanisms and multi-objective constraints.

Table 1 summarizes the main methods determined in the articles selected in this review, each one cited at least 3 times among the papers. Note the most applied method was, by far, Genetic Algorithms with 14 applications. Then, local search appears with 6 studies.

Ant colony optimization, mixed integer linear or non-linear programming and particle swarm optimization presents 4 publications, while, lastly, coral reef optimization were identified in 3 cases. Together, they represent more than half of all compiled works.

Table 1 - The methods

Articles	Genetic Algorithm	Coral Reef Optimization Algorithm	Ant System/Colony Optimization	Particle Swarm Optimization	Mixed integer linear or non-linear programming	Local Search
4	x					
5	x					
7	x					
8						x
9					x	
10	x					
11	x					
12	x					
13	x					
14	x					
15		x				
16		x				
18	x				x	
19				x	x	
20				x	x	x
22						x
25	x					
29			x			
31				x		x
32						x
42	x		x			
44	x					
47				x		
48		x				
55	x					
56			x			x
57	x		x			
Total	14	3	4	4	4	6

Source: The authors.

Note: Articles not mentioned in the table correspond to those that also carried out systematic reviews/survey of this content, were used as reference or their methods had fewer citations, being less expressive. This does not diminish the importance of your findings. Simulated annealing and tabu search, per example, didn't appear a lot, but they are mentioned in the theorical references of the articles as knowing methods.

It is worth mentioning that all these studies present their own peculiarities, adjusting the algorithms used to suit their realities. Among these specificities that seek to find optimal solutions, the combination of models and the use of computational and technological tools stand out. Convex and semidefinite optimization frameworks, niching and e-constraint method, Wang-Landau sampling algorithm, CAD, bay structure, neural networks, between others, are some of the many diverse methods and tools discovered in the study that contribute to the development of best practices in facility rearrangement.

5.5 Advantages

In general, the results found in all articles gathered follow the same pattern. According to Jankovitz *et. al* (2011), his methodology consistently produces competitive and often improved layouts for well-known large instances when compared with other approaches in the literature. The decomposition-based algorithm developed by Guan *et al.* (2020), also, is able to find the optimal solutions in much less time compared with two exact methods. The set of these two parameters, solution quality and the speed of results generation, well describe the benefits of using these unconventional models, bringing organizations more efficiency and, consequently, advantages over their competitors.

6. CONCLUSION

The review of the articles gathered in this study allowed us to conclude that the use of mathematical methods, algorithms and computational models was highly relevant when applied to layout optimization problems. Most of them combined with other tools aiming to reach optimal solutions for each situation. In order to spread beneficial management practices, it is recommended getting used to these models, as they improve the efficiency of organizations making them more competitive in the fierce market.

The status and content of surveys are typically focused on unequal areas and single row cases. Furthermore, they are not flexible to the most diverse layout scenarios that can be found, being efficient in cases where the characteristics of the problem classes are similar.

Advantages achieved when new technologies assist in the layout development process reveal that revolutionary tools such as augmented reality will be widely used to simulate events and plan changes, avoiding errors and rework.

Taking into account that all methods and tools present some type of disadvantage or weak point in relation to their application, it is up to future research to develop new combinations of algorithms and harmonize the capabilities of each tool to achieve increasingly better results. Presenting solutions that are flexible and encompass several different scenarios can be interesting too, whereas the works always refer to a single type of layout. In addition, inserting new performance measures will make jobs richer and more qualified, as well as paying attention to poorly studied contexts, like multi-row FLP problems, and future technologies that meet these needs.

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