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Integrated and interactive method for solving layout optimization problems

Julien Bénabès, Emilie Poirson *, Fouad Bennis

LUNAM, IRCCYN, 1, rue de la Noë, 44321 Nantes, France

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ABSTRACT

Having a significant impact on the design of many products and industrial systems, such as the subdivision of a ship, the layout of facilities in a plant or further still the assembly of parts of a mechanism, layout design optimization is at the heart of scientific issues. The design of an optimal layout solution is a critical and complex task due to the increasing demands of designers working on varied projects. This paper proposes an integrated approach to solve layout optimization problems, from the needs expressed by the designer to the creation of an ideal solution. This generic and interactive method is based on a design process divided into four steps: the description, the formulation, the solving of the problem, and the final decision. This process is based on a multiobjective modular optimization strategy that combines a genetic algorithm with local optimization modules. The method described in this paper is interactive because the designer participates in all process's steps. For example, in the final decision step, the approach includes an interactive environment in order to let the designer choose and improve an optimal solution according to his personal judgment and expertise. The global method is applied to an industrial problem which deals with the search for an optimal layout of facilities in a shelter.

1. Introduction

Layout problem is inherently a multidisciplinary task. It covers all the aspects of the product design life cycle from the conceptual to the detailed stage and makes necessary the collaboration between experts of technical and economical disciplines. Layout problems are usually considered as optimization problems. Although there are, in layout design literature, different definitions of layout optimization problems (Cagan, Shimada, & Yin, 2002; Yi, Fadel, & Gantovnik, 2008), the key idea is always the same: given a set of free form components and an available space, a layout problem consists of finding the best arrangement (location and orientation) of components satisfying geometrical and functional constraints and achieving design objectives. This generic definition can be adapted to all real-world applications. For example, Drira, Pierreval, and Hajri-Gabouj (2007) and Wäscher, Haubner, and Schumann (2007) have adapted the definition of a layout problem to their respective research domain, meaning the facility layout design and the cutting and packing problems. Solving layout optimization problems is critical hard because layout problems are generally considered as non-linear and NP-hard optimization problems. Problems are intrinsically harder than those which can be solved by a non-deterministic turing machine in polynomial time. Consequently, designers need efficient tools in order to formulate and solve these optimization problems and make a final decision. As far as we know, there is no existing paper in literature which proposes a generic integrated method for solving layout problems.

Regarding the optimization algorithms used to solve layout problems, one finds multiple single or multi-objective approaches in two or three dimensions Cagan et al. (2002). Traditional gradient-based approaches can be used for simple layout problems. For more complex real-world applications, some stochastic algorithms are required to avoid local optima. For example, some optimization strategies use genetic algorithms (Aiello, La Scalia, & Enea, 2012; Al Hakim, 2000; Grignon & Fadel, 2004; Islier, 1998; Yi et al., 2008), simulated-annealing algorithms (Sahin, 2011; Szykman & Cagan, 1997) or extended pattern search algorithms (Su & Cagan, 2000). Most search algorithms are developed for a specific problem and they provide an effective optimization strategy for it. However, they are not generic and cannot be adapted to a lot of layout problems. Some of recent studies deal with the search of efficient generic algorithms for solving layout problems. Jacquenot et al. propose in Jacquenot, Bennis, Maisonneuve, and Wenger (2009) an hybrid algorithm based on a genetic algorithm coupled with a separation algorithm. A variant of this approach is also presented in Benabes, Bennis, Poirson, and Ravaut (2010).

In the solving process of layout problems, the direct participation of the designer in the construction of an ideal solution is an essential stage. Non-formal analysis has to be integrated in the

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* Corresponding author. Tel.: +33 2 40 37 69 57.
E-mail addresses: emilie.poirson@ec-nantes.fr, emilie.poirson@irccyn.ecnantes.fr (E. Poirson).

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search for an optimal design. In general, the designer almost always has to correct either the design variables, the optimization criteria, and so on. We can find in Michalek and Papalambros (2002) a significant contribution to the integration of the designer in the layout optimization process. The method is applied to architectural layouts, and designer suggests to the optimization algorithm initial solutions which take into account his own expertise. Moreover, interactivity with designer can be used to insert qualitative fitness or user perceptions in the design process (Poirson et al.). In layout design, Brintrup et al. have already developed an interactive genetic algorithm based framework for handling qualitative criteria in design optimization (Brintrup, Ramsden, & Tiwari, 2007). Also, the designer can interact with the optimization process in order to make a final choice on the alternatives proposed by the optimization algorithm. Interactive decision making environments are necessary to make this final choice (Balling, Buffalo, & NY ,; Stump, Yukish, Simpson, & Harris, 2003). According to the analysis of existing work on layout optimization, this paper proposes an innovative integrated and interactive optimization method for solving layout problems, from the description of the layout problem to the final decision. The paper is organized as follows. Section 2 is dedicated to the description of the different steps of the method. In Section 3, the method is applied to an industrial layout application. Section 5 concludes this paper. Q6

2. Presentation of the method

2.1. General view of the methodology

Cagan et al. already proposed in Cagan et al. (2002) a schematic representation of the major constituent parts for solving a generic layout optimization problem but not focus on the solving process. Fig. 1, using the structured analysis and design technique (SADT), illustrates another representation of layout optimization by including the different steps of the solving process. The integrated method, proposed in this paper, is based on this representation. The method is divided in four steps: the description, the formulation, the solving of the problem and the decision making. The first two steps consist in writing the optimization problem, meaning the optimization variables, the constraints and the objectives, taking into account the different requirements of the designer. A geometric model of the layout is created, based on an innovative division of layout components in material and virtual items. Then, an optimization algorithm is used in order to solve the optimization problem. A set of Pareto-optimal solutions is generated if a multi-objective formulation of the problem is adopted by the designer. The final step allows the designer to make a final decision on the optimal solutions proposed by the algorithm. This decision is made according to the quantitative performances of the Pareto-optimal solutions and the personal judgment of the designer. Next sections will detailed the different steps.

2.2. Description and formulation of layout problems

Describing the problem is an essential step in the process of optimization. However, this is much more difficult than it seems, to equate the different components between them.

2.2.1. Description of layout problem

The layout problem description is the first step of the global layout solving process. This step is usually defined by the engineering experts who well know the global performances of the product or the system. The layout problem description includes the description of the container, the components and the expert's requirements. In layout problems, one finds at least one container and multiple components which have to be placed into the container. Generally, layout components are very different according to their shape, their size and their functional properties. In order to take into account these differences, we propose to divide layout components into two categories: the "material" and "virtual" components, defined as:

- **material component**: with a mass, it cannot overlap with another material component (in 2D). Layout components are generally considered as material components in layout literature (Drira et al., 2007; Yi et al., 2008);
- **virtual component**: without mass, it can overlap with some material or virtual components, according to the designer's requirements. The passages, described in the layout problem presented in Lee, Han, and Roh (2003) can be considered as virtual components.

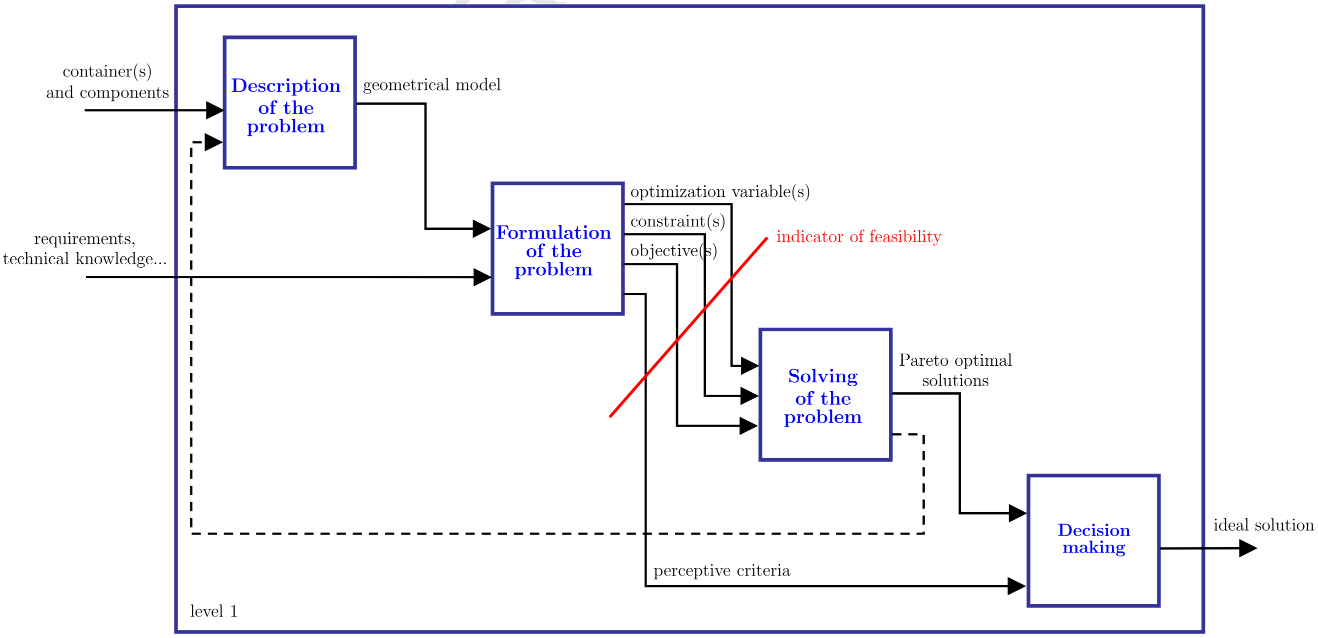

Fig. 1. SADT of the integrated layout optimization method.

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