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THE EVOLUTION OF RECTANGULAR BIN PACKING PROBLEM – A REVIEW OF RESEARCH TOPICS, APPLICATIONS, AND CITED PAPERS

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Abstract. Bin packing problem (BPP) is one of the fastest-growing research issues within the field of combinatorial optimization. Over the last years, several studies carried out various BPP variants, mathematical models, and proposed methods to the BPPs. The classical BPP consists of packing a set of rectangular items in a minimum number of rectangular bins while respecting some constraints.

Throughout the years, an improved typology was introduced by Wäscher et al. (2007), providing an excellent instrument for the organization and categorization criteria that defined the problem categories different from those of Dyckhoff (1990). Several early literature reviews have been conducted on various aspects of related packing problem variants.

The contribution of this paper is to provide a comprehensive and refined taxonomy intended for BPPs. In addition to that, it is an up-to-date review based on a chronological taxonomy of the literature and depicts further research horizons.

This systematic review allowed us to identify other characteristics and constraints, based on Wäscher's original ideas, mainly distinguished according to real cases studies. The detailed analysis provides a valuable framework for understanding the research gaps for future studies that should be acknowledged while proposing and solving new extensions.

1. **Introduction.** The standard Bin Packing Problem (BPP) is one of the oldest and most thoroughly studied problems in the field of combinatorial optimization. Indeed, since 1939, BPP has gained popularity as one of the most challenging problems. Over the last 30 years, many academic research on the BPP have been

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conducted to study more comprehensive models, come up with new approaches, and reach better results.

Given n items, each having an integer weight (or size) w_i $(i = 1, \ldots, n)$, and an unlimited number of identical bins of integer capacity C. The basic BPP consists of orthogonally packing all the items into the minimum number of identical bins so that the total weight packed in any bin does not exceed the capacity. One of the earliest scientific mentions dates back to the year 1960 when [149] formulated the first integer linear program (ILP) for the basic BPP. A mathematical model is expressed as follows:

$$\min \sum_{j=1}^{n} y_j \tag{1}$$

S.t

$$\sum_{i=1}^{n} c_i x_{ij} \leq C y_i; \forall j = 1, \ldots, m \tag{2}$$

$$\sum_{j=1}^{n} x_{ij} = 1; \forall i = 1, \ldots, n \tag{3}$$

$$x_{ij} \in \{0, 1\}; \forall i = 1, \ldots, n;\ \forall j = 1, \ldots, m$$

$$y_j \in \{0, 1\}; \forall j = 1, \ldots, m$$

where x_{ij} is a decision variable, equal to 1 if the item i is placed at bin j; otherwise, 0. y_j is a decision variable equal to 1 if the bin j is used; otherwise,0. The objective function (1) minimizes the number of the used bin. Inequalities (2) state that for each bin j, the amount packed cannot exceed the width of the bin, and constraint (3) ensures that each item i is packed.

The number of academic publications on this problem has increased extensively. The most widely considered among BPP variants is called Two-Dimensional Bin Packing Problem ($2D$-BPP) due to its frequent occurrence in real-world applications. A $2D$-BPP instance consists of an unlimited number of identical bins of Width W and Height H. Given also a set of n items where each item is characterized by its width w_i and its height h_i. The aim is mostly to minimize the number of bins used to pack all the items (See Figure 1).

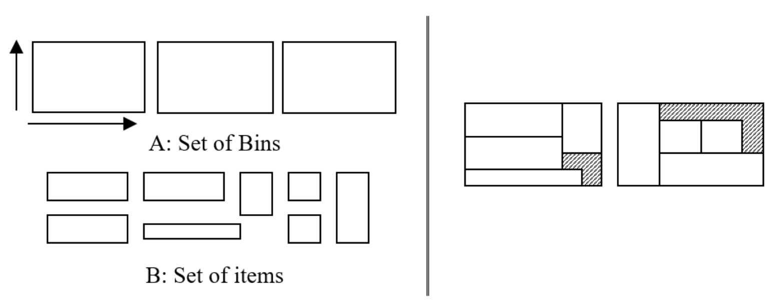

FIGURE 1. Example of bin packing

[253]'s typology are particularly important as it introduced new categorization criteria allowing researchers to assign their problems to specific categories. More

recently, the BPP scenario has shifted from the classic case towards more complex ones. This trend was stimulated by the complexity presented in real-life applications. This breakthrough has pushed researchers to pay closer attention to new variants emerging in real-life industrial applications, including additional constraints and objectives that are more ambitious. As a result, several additional highly significant constraints in practical situations have been subjected to careful examination. This paper reviewed the state-of-the-art BPP literature highlighting the new characteristics suggested in recent research papers.

In this respect, aims can be stated as follows: The first is to provide a relevant classification of the most popular bin packing problems. We build this taxonomy according to the highlighted criteria suggested in recent research papers, more closely related to real-life cases, and we review the BPP with rectangular objects (MBSBPP and SSBPP) based on their variants, scenario characteristics, and physical characteristic. Secondly, we give the researchers a valuable starting resource for searches. Last but not least is to identify open challenges for researchers and guide future development efforts.

The remainder of this paper was structured as follows: Section 2 explained how we delimited our research focus and selected particular academic contributions reviewed in this paper, following [253]'s typology. Section 3 provided definitions of the hierarchical classification attributes. A statistical analysis of the respective data was introduced in Section 4. Finally, Section 5 concluded this review paper and paved the way for future research trends and issues.

2. **Insights in BPP literature: A brief overview and analysis.** This section sums up the key insights we gained during our study concerning the definition of the problem and the links between the basic BPP and its variants. For the cutting and packing ($C\&P$) area, the first typology was presented by [83], where a classification scheme, based on four characteristics, namely dimensionality, kind of assignment, the assortment of large objects, and an assortment of small items, is suggested. Nevertheless, this typology was not universally accepted. To overcome the weaknesses of the old classification, [253] proposed an improved typology by introducing more consistent terminology and refined categorization criteria. Their work sought to catch all the $C\&P$ problems characteristics in the classification scheme.

Out of the diverse problems discussed by [253], the packing problems classification and representation depend on the objective based on the minimization of the number, value, or total size of the used bins (or another corresponding auxiliary objective) and on a strongly heterogeneous assortment of small items. On the other hand, the assortment of large objects, which can be identical, weakly, or strongly heterogeneous (see Table 1). A BPP is a combinatorial optimization, and several researchers from different fields have contributed to the research endeavor. The standard BPP problem can be interpreted as follows: A given set of small objects (items) must be assigned to the large objects (bins) such that the given objective function is optimized. The basic objective is usually to minimize the number of used bins.

Beyond this common definition, many BPP variations and extensions were suggested in many papers which can be divided into theoretical papers or case-oriented papers. A large volume of research has been achieved in the area, a significant

Table 1. Problem types – input minimization ([253])

Assortment of small items		**Characteristics of large objects**	
		Weakly heterogeneous	**Strongly heterogeneous**
All dimensions fixed	Identical	Single Stock Size Cutting Stock Problem (SSSCSP)	Single Bin Size Bin Packing Problem (SBSBPP)
	Weakly heterogeneous	Multiple Stock Size Cutting Stock Problem (MSSCSP)	Multiple Bin Size Bin Packing Problem (MBSBPP)
	Strongly heterogeneous	Residual Cutting Stock Problem (RCSP)	Residual Bin Packing Problem (RBPP)
One large object variable dimension(s)		**Open Dimensions Problem (ODP)**	

amount of the research deals with standard BPP (see [113, 176, 178]). Elaborated surveys and taxonomy, concentrate on a particular variant ($2D$-BPP, Cutting problem) are also provided by [174, 175, 82, 19, 240, 201, 259, 237, 143] and more recently by [190] and [69]. Many papers are devoted to reviews of algorithms such as [58, 130, 177, 131, 91].

For this study, we examined over 320 research papers devoted to BPPs that have been published since 1980. The selected papers provided a representative sample of the most significant work. Moreover, the study focused only on papers that were published in high reputed journals publicly available, English papers published in the international journals, edited volumes, and conference proceedings.

We concentrated on publications dealing with refined problem types (see Table 1) as defined by [253] (e.g. Single Bin-Size Bin Packing Problem (SBSBPP), Multiple Bin-Size Bin Packing Problem (MBSBPP), and Open Dimension Problem (ODP)). The literature on the problem variants, as the articles dealing with real cases, have been considered. Therefore, this review did not take papers dealing with irregular bin packing (see, e.g., [61]). These criteria were used as guidelines to delineate the material discussed in this review. Special attention was given equally to papers dealing with the problem extensions and variants. Ultimately, the selection process yielded 250 studies in total, including articles of [83] and [253]. It should be noted that we would apologize for any unintended omission of some relevant articles. Table 2 provides an overview of the development of BPP publications over the period extending from 1980 to 2022.

The bibliography of the BP research is very rich, and most of the studies are concerned with building models and developing methods. It is worth noting that about 50 % of the considered papers were published in highly renowned journals such as EJOR, COR and DAM. As observed in Table 2, the number of BPP publications has increased substantially. The number of published papers in the last three years (2015 to 2022) is almost similar to those published over the preceding four years (2010-2014) and exceeds those published during 2005-2009 period. However, compared to the theoretical papers, fewer studies have been conducted to solve the BPP in practical applications.

TABLE 2. The number of papers on BPP until 2022

Year	**Number of papers**
1980-1989	10
1990-1999	14
2000-2004	23
2005-2009	40
2010-2014	**83**
2015-2022	**80**

3. **Description of the classification.** In this section, we introduced the BPP taxonomy involving the categorization criteria, and we studied the trade-off of adding more constraints that can be used to make the problem more realistic. To this end, we focused on the description (see table 3) and the definition of the taxonomy principal attributes. A trend towards considering complex packing problems with diverse geometries, and closer to reality has arisen recently. Therefore, besides the basic BPP features, some additional characteristics have received increased interest. However, this survey did not cover the differences between BPP variants but rather identified the most important criteria faced in industrial applications. The mentioned attributes are not only the standard features but also those related to the nature of the studied problem. [253]'s typology proved to be an excellent instrument that facilitated communication among researchers and allowed them to assign specific BPPs to the relevant problem categories. Thereby, the following presentation was based first on the categorization of [253], where the typical problems are the following:

- Single Bin-Size Bin Packing Problem (SBSBPP): Packing a strongly heterogeneous set of items into a minimum number of identical bins.
- Multiple Bin-Size Bin Packing Problem (MBSBPP): Packing a strongly heterogeneous set of small objects into a weakly heterogeneous assortment of large objects such that the cost or the value of the used bin is minimized.
- Open Dimensions problems (ODP): Packing a strongly heterogeneous set of items into one large object such that the variable length of the large object has to be minimized.

From this first typology, the taxonomy did not highlight all the differences between variants of the BPP. It was designed according to specific concepts in packing that are frequently presented in industrial applications and aimed at giving the reader a good idea of new extensions and characteristics. Besides, the mentioned attributes are not necessarily the basic BPP features but are associated with the characteristics that alter the nature of the problem. More precisely, the purpose of the taxonomy was not to classify the papers according to all the details but rather to focus on relevant features.

In the following, a detailed description of the classification scheme was introduced: The taxonomy was built hierarchically within two classes. Problems were considered according to the Scenario Characteristics and physicals Characteristics. Below each of these two classes, the most distinguishing attributes were enumerated. They revealed whether the problem under study closely simulates the real-world scenarios. Thereafter, we described the proposed classification system in details, and specified each characteristic and gave some relevant references (see Table 3).

Table 3. A BPP classification

<table>
<tr><th colspan="2">1. Physical characteristics based on the structure</th></tr>
<tr><td>1.1.Items</td><td>Strongly heterogeneous items</td></tr>
<tr><td rowspan="4">1.2.Bins</td><td>1.2.1. On large objects</td></tr>
<tr><td>1.2.2. Several large objects</td></tr>
<tr><td>Identical bins</td></tr>
<tr><td>Weakly heterogeneous bins</td></tr>
<tr><td rowspan="3">1.3.Dimensionality</td><td>1.3.1.One-Dimensional (1D)</td></tr>
<tr><td>1.3.2.Two-Dimensional (2D)</td></tr>
<tr><td>1.3.3.Three-Dimensional (3D) or more</td></tr>
<tr><th colspan="2">2. Scenario characteristics based on reality</th></tr>
<tr><td rowspan="2">2.1.Objective</td><td>2.1.1.Single objective</td></tr>
<tr><td>2.1.2.Multiple objectives</td></tr>
<tr><td rowspan="4">2.2.Problem data</td><td>2.2.1.On-line</td></tr>
<tr><td>2.2.2.Off-line</td></tr>
<tr><td>2.2.3.Stochastic</td></tr>
<tr><td>2.2.4. Dynamic</td></tr>
<tr><td>2.3.Constraints</td><td>2.3.1.Basic Geometric constraints : Containment, Overlap
2.3.2.Reaslistic Additional constraints
a. Rotation
b. Guillotine
c. Stability
d. Precedence
e. Fragility
f. Conflicts</td></tr>
</table>

3.1. **Physical characteristics based on the structure.** This section described the sublevels and defined the characteristics of each category, presented in Table 3. The problems, by and large, are arranged by type (SBSBPP, MBSBPP, and ODP) and by dimensionality criteria. The problem types are defined depending on the characteristics of bins and items.

3.1.1. *Items.* In the cutting and packing field, a distinction is usually made between weakly and strongly heterogeneous items. Indeed, an item set is considered as weakly heterogeneous if it consists of only a few distinct item types. However, strongly heterogeneous items set has more distinct item types, but very few individual items per type. It should be noted that this paper dealt only with strongly heterogeneous sets (see Table 1).

3.1.2. *Bins.* Concerning the large objects assortment, we considered the case of one large object, where dimensions vary and are considered as an ODP. Furthermore, our study rather focused on the case of several large objects regarded as identical or weakly heterogeneous. Therefore, the case of the strongly heterogeneous assortment of large objects was not considered in this work.

- *One large object*
  According to the literature, the ODP requires packing a given set of small items of given two or more dimensions to one large bin. Problems of this kind have also been named Strip Packing Problem (SPP), in which a set of small items has to be assigned on a bin. While the width of the large

object is fixed, its length is variable and has to be minimized. Recently, [221] presented metaheuristics for solving the two-dimensional strip packing problem (2D-SPP). The problem consists of packing all the items into the object in a non-overlapping way, such that the resulting packing height is a minimum.

- *Identical bins*
  We identified the large objects with identical sizes. According to [253] typology, this is a representative of the SBSBPP problem type, in which all dimensions are fixed in one or more dimensions. In this case, the One-Dimensional BPP ($1D$-BPP) requires packing a given set of small items of given weights to a minimum number of large objects (bins) of identical size (capacity) so that the total capacity of the small objects does not exceed the capacity of each bin. Extensions of the Classic $1D$-BPP into two and more geometric dimensions has given rise to the $2D$-BPP, also called Two-Dimensional Finite Bin Packing Problem and to the Three-Dimensional BPP ($3D$-BPP), where items are assumed rectangular boxes fitted orthogonally into a minimal number of rectangular containers of identical sizes. This problem is examined in the works of [236, 113, 239, 122].
- *Weakly heterogeneous bins*
  An extension of the $1D$-BPP (respectively for 2D and 3D) is that of packing the rectangular items into weakly heterogeneous rectangular bins, also known as a variable-sized bin-packing problem (VSBPP). This class of problems is a $1D$-MBSBPP introduced by [253]. [99] were the first to investigate the VSBPP where each bin type is in unlimited supply and characterized by specific costs and size. All the items have to be assigned to bins, and the total costs of the used bins have to be minimized. The VSBPP is comparatively not as well-studied as the standard BPP although the related variants are investigated in both Online and Off-line versions. Recently, [90] has studied VSBPP with general costs. The goal is to assign the items to bins so that the total cost is minimized. The author has also designed an AFPTAS for the problem by introducing new reduction methods and separation techniques, thus providing new insights into this interesting problem. For further information, the reader is referred to [124, 183, 119, 203, 127, 92, 267, 120, 256, 154, 215, 76, 148].

3.1.3. *Dimensionality.* Dimensionality is the most important BPP characteristic. It stands for the minimum number of dimensions of the real numbers that are necessary to describe the geometry of the patterns. This criterion is mentioned in the two reference typologies [83] and [253]. The rich body of literature on the BPP variants includes several generalizations where most defined problems with one, two, three-dimensional, or more. The classical one-dimensional Bin Packing Problem ($1D$-BPP) requires a set of items to be stored in the minimum number of the being used bins, each with the same capacity. This extension has been well-studied, and various methods have been applied to solve it. This variant was also reviewed by [189, 113, 155, 158, 236] and has been further examined by [184, 212, 239, 12, 160, 180, 50].

The two-dimensional Bin Packing Problem (2D-BPP) is the most thoroughly studied variant. It was proposed by [29], and consists in placing items into the minimum number of bins. Most contributions in the literature are devoted to the case where the items to be packed have a fixed orientation. For a comprehensive and recently annotated bibliography, the reader is referred to [115, 219, 29, 70, 252, 163, 179, 59, 213, 56, 238]. Worth mentioning is that the $2D$-BPP requires two additional characteristics, namely (1) Orientation and (2) Guillotine cuts. The former states that each item may have a fixed orientation or can be rotated by 90° while the latter stipulates that the items can be obtained through a sequence of edge-to-edge cuts parallel to the edges of the bin; otherwise the cutting is non-guillotine. For a bibliography on the BPP variants allowing rotations (usually by 90°) and/or guillotine cuts constraints, the reader may consult the following papers of [175, 178, 37, 169, 218, 226, 69, 98, 46, 31, 181, 139, 269, 30]. Detailed surveys on modeling and solution methods can be found in [82, 130, 248, 174, 175, 237, 3].

The next sub-level is the three-dimensional Bin Packing Problem ($3D$-BPP), which attempts to pack boxes into containers orthogonally without overlapping. Often, both of the orientation and guillotine constraints have to be considered in $3D$-BPPs. Although the literature devoted to this variant is scarce the interested readers may refer to several published papers (see [208, 176, 126, 181, 261, 6, 147, 67, 5]).

3.2. Scenario characteristics based on reality.

3.2.1. *Objectives.* Many BPP variants have been studied over the years to minimize the number of bins, the cost, and the height of the open bin are the main relevant objectives studied in the literature. Most of the works set a unique goal. However, in practice, the number of bins is limited, which makes the decision maker face a multi-objective problem. Thereby, depending on the chosen application, other objectives can be defined and extended according to real-life applications (see, for example, [203, 127, 151, 13]). Recently, the study of the multi-objective BPP (MOBPP) has progressed noticeably. The most common objectives include minimizing the number of bins, the total cost, the conflicts between items, and the maximum height of a bin, in addition to maximizing the total weight and the loading priority. When multiple objectives are identified, some of them might often have a conflicting relationship, requiring adequate algorithms to ensure some trade-off between them. For a survey on the MOBPP, the reader is referred to such works as [254, 134, 146]. BPPs with two or more criteria have received considerable attention, but there is still much research to be done. Recent solution methods, on the MOBPP, can be found in [254, 134, 146, 96, 105, 123, 135, 170, 192, 117].

3.2.2. *Problem data.* Data can be classified into four classes: deterministic, static, stochastic, and dynamic. In a deterministic (Offline) packing situation, all problem data are known in advance. Thus, all information about the bins and the size of items is known before the placement process begins. By contrast, in a static packing situation (online), some information, usually about items, is supplied in the form of probability distributions. Thus, in the Online version, items arrive one by one, and each item must be assigned immediately to the bin without prior knowledge of the characteristics of future items. Most papers in this review examine BPPs with deterministic data. Among these authors, we can mention [30, 219, 175, 183, 12, 201]. As for the online BPP variant, where items are introduced one by one to be packed into unit-sized bins, it was studied in the following papers: [16, 267, 94, 59] and more recently the papers by [14, 15, 108, 51].

Furthermore, in the case of dynamic packing, deletion and addition of some elements are allowed during the time at each packing step while the stochastic data assumes that probability distributions are already associated with them. [60] introduced the idea of Dynamic Bin Packing. Quite a few publications are devoted to the study of the numerous versions of Static and Dynamic Packing problems. Interested readers may consult the studies of [28, 93, 64, 71, 89].

3.2.3. *Constraints.* A large body of research focused on standard BPP. With an increased ability to flexibly pack complex and diverse geometries in industrial applications, the requirement to handle complexity in the packing process arises. This section aimed to introduce the constraints proposed by [83] and [253], and interpret some of the conditions introduced through the resolution of industrial applications, such as those in transportation. We discussed both basics and additional constraints encountered in real-life situations. Several constraints that express relations between the small objects and the bin have to be taken into account when modeling the problem to guarantee they are respected.

Basic Geometric constraints: According to the literature, there are frequent constraints for all placement issues. Two conditions are always present and must be verified to consider a feasible arrangement in a standard BPP; these are the non-overlapping constraints between Items, and the constraints that each item is placed in the bin it belongs to. The first stipulates that each item lays absolutely within a container parallel to its sidewalls. The second entails that any item inside the same bin must not overlap with one another.

Realistic Additional constraints: Practical issues that appear in real-life scenarios, such as the assignment of some items to specific bins, have not been correctly considered in BPP research. Recently, several factors have led researchers to pay more attention to packing operations with realistic constraints, and to look for ways to make them more efficient. These constraints express relations either between bin and items or within the packing process. In the following, we reviewed the different kinds of additional BPP constraints, which usually occur in practical applications.

- *Rotation and Guillotine constraint:*
  The orientation and guillotine constraints are the most frequently addressed in the literature, particularly in 2D-BPP and 3D-BPP. Several algorithms have been proposed for each combination of these constraints. The rotation constraint means that the items may either have a fixed orientation or rotated by 90°. In the literature, most contributions are devoted to cases where the items have a fixed orientation. (See, for example, [85, 217, 178, 29, 37]). Variants allowing rotations, however, have been subject of only a very limited number of papers (see [37, 175, 181, 48]).

  The rather optional Guillotine constraint requires that all packed items are reproducible by a sequence of edge-to-edge cuts parallel to the bin edges. There are a few papers on 2D-BPP and 3D-BPP with guillotine cut constraints such as those published by [201, 181, 240, 145, 46, 218, 269, 196, 172]. [178] introduce four possible cases related to those two constraints (rotation and guillotine):
  - RF: items rotated by 90° (R) and the guillotine cut constraint is not imposed (F);
  - RG: items rotated by 90° (R), the guillotine cut constraint is imposed (G);
  - OF: items orientation is fixed (O), the guillotine cut constraint is not required (F);
  - OG: items orientation is fixed (O), the guillotine cut constraint is imposed (G).

It is true that more and more constraints are imposed in real-life situations. In fact, such constraints as rotation and guillotine are quite common in industrial applications and often considered in most publications. Nevertheless, other kinds of constraints such as those related to stability and precedence have been rarely studied, as we will see in the following.

- *Stability constraint:*
In the literature, the stability constraint is considered, mainly in 3D-BPP and in loading problems, as well. Load stability is one of the most important types of restrictions since unstable loads may result in a damaged bin (containers, pallets, warehouse) during transportation or storage and in injuries to the personnel during handling the operations (loading and unloading). It is, therefore, necessary that the base of the current item be supported by objects that have already been placed or by the bin floor (see [243, 42, 142, 77, 244]). In order to ensure the vertical stability, the bottom side of each item needs to be supported by the top face of other objects or by the bin floor ([42, 44, 142, 244]). An extensive analysis of vertical stability can be found in [222].
- *Precedence constraint:*
Generally speaking, precedence constraints correspond to the ranking order relation of items where precedence refers to the relative ordering of bins. The BPP with Precedence Constraints (BPP-P) is a new variant and has drawn a growing attention in recent years. In this type of constraints, another requirement is imposed: packing the items into the bins must be linearly ordered, which ensures that a given precedence is satisfied. It has particular applications in assembly and scheduling issues. The first application is the assembly line balancing problem, studied by [207]. In this context, the assembly line consists of identical workstations (the bins) where the products stop for a period (that is) equal to the bin capacity. The items sizes are the durations of the tasks to be performed, and a partial order is imposed accordingly: this means that the workstation to which item i is assigned cannot be downstream of the one to which item j is assigned. The second application is used in the multiprocessing scheduling studied by [104]. Here, each item corresponds to a unit-duration process having requirement equal to the item size. The given partial order requires that the item i must be achieved before j ends. The goal is then to get a feasible schedule that carries out the set of processes in the least time (number of bins) possible.

  Among the studies that focus on the BPP-P can list those of [234, 10, 79] and more recently [223, 54, 78]. [10], for instance, studied the BPP-P as a particular case of the SPP with precedence constraints. As for [54], they proposed a mathematical model and developed an Iterated Local Search heuristic algorithm whereas [223] and [234] studied the BPP with general precedence constraints.
- *Fragility constraint:*
The Bin Packing Problem with Fragile Objects (BPPFO) is an extension of the classical BPP. In this problem, each object has a fragility value in addition to its size (weight, width, height, etc.). The aim is to pack all the objects into a minimum number of bins while verifying the sum of the items' sizes in each bin is not higher than the fragility of any item in the same bin. The definition of the fragility constraint is straightforward. In terms of weight, a better stability is achieved if the heavier items are placed at the bottom. This

constraint is quite fundamental in practice because it prevents the damaging of the contained products in a fragile box. This feature is managed by different developed strategies, revealed in such works as those of [244, 142, 19, 44], and more recently [57, 32, 43, 205].

- *Conflicts Constraints*
  Besides the previously mentioned constraints, BPPs may differ due to potential conflicts manifested over problem elements. Furthermore, Conflicts constraints are due to the conflict relationship between items and between items-bins. They can be classified into total and partial incompatibility. The BPPC is a generalization of the classical $1D$-BPP, which is a combinatorial problem known as NP-hard. Many BPPC solution approaches are available in the literature. However, very little research to solve this problem of conflicts constraint was conducted. A detailed description of the different conflict types were discussed, in the next section.
  - *Bin-Item conflicts vs. Item-Item conflicts*
    The incompatibility constraints are often faced in practical situations. The first is the item-item incompatibility constraint; it occurs when two items cannot be assigned to the same bin. The second is the bin-item incompatibility constraint and arises when a given item cannot be placed in a particular bin. However, the conflicts considered in the literature on the BPPC are assumed to be principally item-item incompatibility constraints. In [112], the authors discussed the bin-item incompatibility constraints that are inherently present in any server consolidation exercise. Indeed, the authors were the first to study a real case of server consolidation problem (SCP) with the complete set of incompatibility constraints that naturally appears in a server consolidation exercise. The objective was to determine the minimum number of target servers needed after taking care of various restrictions of incompatibility for the problem. They proposed a novel two-stage heuristic algorithm to solve this issue. Similarly, [4] examined the item-item incompatibility constraint where conflicting objects cannot be placed in the same bin, and they proposed a novel grouping genetic algorithm. Recently, [159] have proposed a new Particle Swarm Optimization method to assign operations to resources and periods in the Hospital Group of Territory problem. This problem is an extension of the classical BPP, taking into account item-bin incompatibilities and non-respected due dates.
  - *Total Conflict vs Partial Conflict*
    Further, incompatibility constraints may be classified according to the following aspects: the first one is the total Conflict where conflicting items cannot be packed in the same bin. The second is a partial Conflict, where partially conflicting objects assigned to the same bin, have to be systematically separated by a safe space between them.
    Total Conflict: The first attempt to model $1D$-BPC was made by [106], who used the basic model of $1D$-BPP, then added a new constraint to manage the conflicting items and ultimately proposed a set of lower and upper bounding procedures. The incompatibility constraint is illustrated by a conflict graph, which has one vertex for each item and one edge for each pair of incompatible items. [22] discussed the problem of determining the number of warehouses needed for Storing products (items) where some

of the objects are in conflict with each other and cannot be stored together in the same warehouse. More recently, [199] has extended the $1D$-BPC literature. He proposed lower and upper bounding procedures and an exact method based on a set of covering formulations solved through a branch-and-price algorithm. Furthermore, the first to explore the $2D$-BPC and deal with heuristic methods is the paper of [152]. The objective was to minimize the number of bins used to pack all items and ensure that the contents of any bin consist of compatible items. Besides, [94] studied the $2D$-BPC on specific graph classes and designed approximation algorithms. For more details, the reader may refer to [113, 22, 185, 153, 184, 87].

The Multi-Objective Bin Packing with Conflicts (MOBC) was first introduced in the papers of [151] and [192]. [151] considered a bi-objective version of the 1D-BPC, where their objectives were to minimize the number of used bins and violated conflicts. Likewise, [192] studied a multi-objective version of the $2D$-BPC to optimize both of the total cost and incompatibility among items within bins. In their work, the authors have proposed a goal-programming model to aggregate all the objectives at once. Recently, [25] have studied an assignment problem that generalizes a particular case of a variant of the BPC.

[186] have provided new lower and upper bounds for the offline version of the Variable Sized Bin-Packing Problem with Conflicts (VSBPC). Recently [171] addressed the BPP with Compatible Categories. The study was motivated by last-mile delivery to tiny stores where the delivered items belong to categories that may not be transported together in the same vehicle. They proposed two new mathematical formulations and an efficient variable neighborhood search (VNS) metaheuristic that relies on a simple greedy heuristic to generate initial solutions and efficient neighborhoods as well as problem-tailored shaking procedures.

Partial Conflicts: As mentioned before, the BPP with partial conflicts means that two items partially conflicting may be assigned into the same bin, only if a given safety distance was kept between them. The problem has several obvious practical applications in contexts where geographical location constraints are involved. More recently, [118] introduced the two-dimensional bin packing problem with partial conflicts ($2D$-BPPC). The introduction of this new complication in the $2D$-BPP is due to constraints encountered in real applications, such as hazardous waste, where items may be partially incompatible and have to be separated by a safety distance. In this respect, the researchers developed two heuristics and a multi-start genetic algorithm for the $2D$-BPPC. The first heuristic is the well-known Bottom Left Heuristic (BLH), which, was modified to fulfill the requirement of the new problem. The second heuristic is the Modified Shelf Heuristic Fill-Dynamic (SHF-D) that was introduced by [28]. In this adapted heuristic, the items were divided into sets corresponding to classes. Then, these classes are treated successively by making sure that the contained objects are not incompatible. If necessary, a safety distance is kept when it is impossible to obtain an order that separates each pair of conflicting classes.

4. **Analysis of selected papers.** More than 200 articles, exclusively written in English, were included in this BPP bibliography. This body of research was first divided into practical and theoretical articles, then, depending on the characteristics and the constraints of each problem. This classification was proposed to define generalizations and enrichments of the BPPs and, to pay particular attention to restrictions faced in practice. Many practical problems can either be reduced to the standard BPP or contain the BPP as a subproblem. Therefore, managers and researchers have to meet the challenge of integrating many practical constraints that frequently arise in real-life situations. Table 7 (see Appendix A) lists all the selected papers included in our study, addressing the BPP problem and its different variants, in a chronological order, and identifies the addressed characteristics and the respective constraints. In the following section, we analyzed the research on BPP problems and suggested some future research opportunities.

Each article is classified according to the attributes defined in the above classification (see table 3) (see Table 7, Appendix A). The shaded lines indicate papers, which include a set of instances based on a real-life application. When the attribute is presented in the corresponding paper, the character 'x' is reported in the associated cell. The column 'Number' provides the numbers assigned to each selected article. In what follows, we give the number of the selected paper into square brackets. The column-headed problem type refers to the types of designed BPP according to [253] typology (MBSBPP, SBSBPP, or ODP). The columns Data, Dimensionality, and Objectives, provide what characteristics are assigned to each selected article. The last column headed Constraints indicate whether or not the article includes a constraint and/or a set of constraints that can be based on a real-life application.

4.1. **Consideration of problem types.** Table 7 (appendix A) shows the number of papers dealing with the various problem types considered in our study. In the first place, only problems of input minimization were considered. In addition, it is worth noting that we discussed only the case of the rectangular shape of the small items and large objects. Three problem categories (SBSBPP, MBSBPP, ODP) have been taken into consideration. The packing of a strongly heterogeneous assortment of small items (i) into a minimum number of identical bins (SBSBPP: 187 papers, 74.8 %) were the most frequently addressed and (ii) into a weakly heterogeneous assortment of non-identical size bin of minimal value (MBSBPP: 46 papers, 18.4%) discussed a significant number of times. Also, (iii) the packing into a single large object (ODP: 29 papers, 11.6 %). Besides, problem extensions of the bin packing have been discussed (see figure 2). In the selected papers, $2D$-BPP was studied more deeply than the other variants ($1D$ and $3D$). Indeed, 126 studies (56.46%) are devoted to $2D$-BPP and its variants ($2D$-SPP, $2D$-VSBPP), 97 (38, 8%) treat the $1D$-BPP, and only 45 (18 %) papers deal with the $3D$-BPP.

Furthermore, in contrast to the Off-line version (236 papers), little attention has been paid to Online BPPs as this issue was dealt within just 18 studies (7.2%) of the selected publications. Finally, unlike the multi-objective case, the mono-objective BPPs (94%) have been studied extensively. Indeed, only 19 (7.6%) papers aimed at minimizing the number of used bins coupled with other additional objectives (conflicts, cost, etc.).

4.2. **Consideration of constraints.** Table 4 displays the number of investigated papers ($N = 220$) related to the frequency of different constraints. Almost half of the reviewed publications (122 out of 250 papers; 48.4%) addresses unconstrained

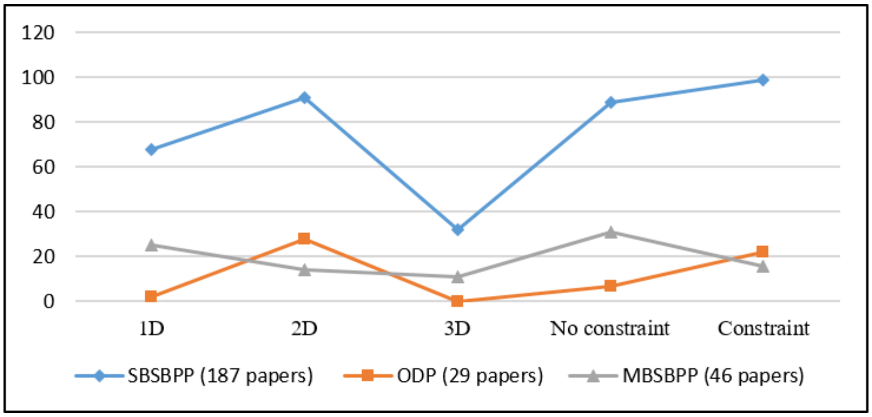

FIGURE 2. The distribution of problem types according to addressed characteristics (Dimensionality, constraints, No constraints)

problems. Apart from the basic geometric feasibility conditions, solutions to the problems that contain additional constraints (such as the stability precedence and conflicts constraints) are scarce when compared to the total number of publications. More specifically, the rotation constraint is considered in almost 64 studies (25.6%). According to the literature, this constraint is often introduced to reduce the time-complexity of algorithms or, further, to minimize the number of used bins. While surprisingly enough, the guillotine constraint is addressed in only 33 papers (13.2%).

TABLE 4. Number of papers where the constraint types have been discussed

Constraints type	**Number of papers** ($N = 250$)
No constraints	122
Orientation	64
Guillotine	33
Precedence	28
Fragility	11
Stability	14
Conflicts	29

In general, works introducing a large number of constraints are still scarce. Among the 250 publications, some studies include three constraints investigation and only two papers includes four constraints (see Table 5). Furthermore, it should be noted that some articles were selected more than once as they studied different problem types at the same time.

TABLE 5. Number of papers where the constraint types have been discussed

Number of Constraints	0	1	2	3	4	5	6
Number of papers ($N = 232$)	122	84	32	7	2	0	0

In opposite of the large volume of work concerned with rotation and guillotine constraints, only a few studies dealing with practical constraints have been published. As can be observed in figure 3, the repartition of constraints is different from one year to another. As seen in figure 3, research on rotation and guillotine constraints is omnipresent in BPP literature and is on the rise. Similarly, it should be pointed out that papers published from 1980 to 1999 did not pay appropriate attention to constraints encountered in practice, which is not the case with the growing trend in the period from 2000 until 2022.

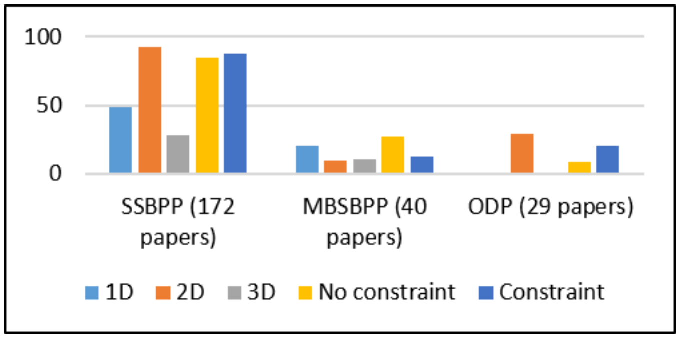

FIGURE 3. % of BPP constraints through the years

Rotation and guillotine constraints are approached in a significant number of contributions. Surprisingly, such constraints as stability, precedence, fragility, and conflict are hardly treated at all. For instance, only (11.2.5%) 28 contributions have considered the precedence constraint. However, conflict constraints (conflict between items and conflict between bins and items) have been discussed in 29 papers. Furthermore, the total conflict issue has been addressed in 26 papers (10.4%) but only three publications deal with partial incompatibility. On the other hand, the fragility and stability constraints are addressed in only 25 (10%) papers.

4.3. **Consideration of constraints in real applications.** Improving the packing process in the industry has become challenging. Researchers have produced collaborative approaches to reduce costs and limit waste while guaranteeing feasible packing and verifying some of the realistic, supplementary constraints. In this part, we focused on the articles dealing with practical cases. Indeed, among the reviewed publications, 30 out of 250 papers are devoted to practical situations. The BPPs, that model several real-world applications (called as real-world BPPs), are mostly concerned with the $2D$-BPP and $3D$-BPP. Indeed, thousands of BPPs may exist in new (even unexpected) real-life situations, generating new variants with additional characteristics and constraints. Hence, future BPP research will deal with more difficult and challenging problems, to devise more complex solutions. In the light of the 30 selected papers, it was noticed that besides the physical constraints, many additional constraints may occur and, thereby, extend the BPP formulation. For this reason, we do not pretend that we collected all the available case studies in the literature, but we believe that we identified the most relevant works. In what follows, we listed the main applications, taking into account the constraint types, and we provided some relevant references. Table 6 provides an overview of

BPP variants related to the practical applications and the most important published case studies. Most of the published papers are concerned with storage and packing (see No: 53, 76, 82, 98, 112, 128, 131, 136, 143, 173, and 224 in Table 6) and the 'container loading problem' (see No: 1, 9, 58, 53, 75, 104, and 146 in Table 6). In fact, for efficient handling and transportation, an optimal packing of cargo into pallets has to be further considered. Besides, potential applications include the 'cutting problem' (No: 94, 126, 136, 147 and 193 in Table 6), the 'Assembly Line Balancing' (see No: 75, 97, and 184 in Table 6), and the 'scheduling problem' (see No: 15, 86, 91, 109, and 173 in Table 6). All the applications were viewed and modeled as a BPP. The treated practical constraints depended on the real-world situation. The case studies related to practical BPPs focused more on the integration of several types of constraints. In general, practically-oriented works introducing a large number of restrictions are still scarce. Among the 30 publications, 14 papers (46.67%) addressed such unconstrained problems and 16 include studies with additional constraints that can be categorized as follows: 9 papers deal with orientation constraint, 2 with guillotine constraint, 8 with precedence, 3 with fragility, 3 with stability, and 4 with conflicts. Furthermore, it should be noted that some research work includes studies dealing with more than one constraint.

According to the recent developments in the packing literature, BPP has appeared as a tool for modeling problems with real-world conditions, especially in transportation. This has led to a new variant taking into account the uncertainty. In this sense, [64] have considered a real capacity planning problem in logistics and have derived a two-stage stochastic formulation with recourse. The problem was presented as the Variable Cost and Size Bin Packing Problem with Stochastic Items, explicitly taking into consideration the uncertainty related to the items. Here, the bins included pre-existing capacity plan, are chosen in advance without the exact knowledge of which items will be available for the dispatching. Uncertainty in BPP appears also in [65], where it is necessary to predict four to six months in advance the allocation of goods to a minimum number of containers of different capacities. The volumes of delivered goods have random deviations around the planned values. The context of BPP under uncertainty appears particularly in the domain of supply-chain management. For further information, the reader can be referred to [168, 65, 73, 74, 72, 75].

5. **Conclusions.** The importance of BPP studies is reflected in an increasing number of papers during the last decade. Indeed, improving the packing process generates several advantages, such as reducing costs incurred by the used resources (containers, objects.) and reducing significant CO_2 emissions into the environment. Furthermore, there is a clear trend towards considering more complex and integrated problems. A growing interest focusing on the objects and bins features, considered objectives, and, more particularly, on additional constraints can be remarked.

In this paper, a general taxonomy for BPPs has been proposed. Many Articles have been classified and analyzed. Moreover, the developed taxonomy can be updated as new industrial challenges appear as recent attributes could be added. Therefore, our review tried to comprehensively highlight the inclusion of various constraints encountered in practice, which we believe will be helpful to many researchers who are still intensively studying this area.

Table 6. Number of constraints considered in the reviewed papers

No.	Papers	Real world Applications
1	[102]	logistics company that loads and ships hundreds of trucks
9	[123]	A direct-shipping system in the food and beverage industry
15	[258]	The task allocation problem of aircraft maintenance
50	[138]	The Challenge Renault/ESICUP 2015
52	[197]	The fruit company in Rio Negro
53	[198]	A Portuguese trading company
58	[246]	The Renault for the 2014/2015 ESICUP challenge
70	[101]	The Machine Reassignment Problem
75	[211]	Assembly design problem
76	[231]	The Renault / ESICUP challenge
82	[262]	The pharmaceutical industry
86	[88]	The Faculty of Economics and Management Sciences of Sfax
91	[200]	An Engine Assembly Line
94	[249]	The Steel Industry
97	[242]	Cellular automata (CA)
98	[141]	The ship placement problem
104	[42]	The industrial beanTech
109	[204]	A Thai Seasoning Company
112	[192]	The industrial Tunisian Foam Company
126	[161]	The production of wind turbine flanges in the open die forging industry
128	[252]	The industry company
131	[194]	The industrial Tunisian Foam Company
136	[18]	Two real life problems from two industrial companies.
143	[195]	The industrial Tunisian Foam Company SOTIM
146	[164]	The air cargo industry.
147	[225]	The roofing industry and the construction of packing boxes
173	[232]	The automobile industry
184	[234]	The Assembly Line Balancing Problem
193	[23]	The Steel industry
224	[39]	A municipal building, a land allocation problem

Research advancements have been discussed and categorized in the light of additional characteristics and through an extensive study of applications and restrictions. The primary objective of this survey is not just to give a structured review of the BPPs, but we expect that it will serve as a helpful starting resource for researchers. Further, we note that solving BPPs can have a major impact on environmental performance. Indeed, BPP has a strict relation to numerous real applications such as container loading, warehousing, scheduling.

Even if the BPP seems to be well covered, there are still some research gaps, which must be filled. Therefore, the promising areas of further research should be indicated as follows:

- Analysis of other BPP variants, since some variants are not very explored, like the 3D-BPP.

- Consideration of the multi-objective version and dynamic problems. As we know, it is not always the case in real applications where uncertain information about the bins and the size of items. Thus, there is a need to look at stochastic and dynamic studies of the BPPs.
- BPP with uncertainty on item and bins characteristics can also be a starting point for future research.
- Discussion of real-world situations is always needed without neglecting any of the known constraints. The field is now open to innovation. Moreover, other variants, which involve additional constraints, seems to be still uncovered.
- In addition, there is still space for combined constraints, like online BPP with conflict and time packing constraints. Investigation in such combinations is welcomed.

6. Conflicts of interest.

The authors declare that they have no conflicts of interest.

7. Appendix A.

See Table 7

TABLE 7. Classification of the selected papers addressing the BPP problem and its variants

No.	paper	Problem type	Data		Dimensionality			Objective		Constraints						
		Rectangular Shape	On-line	Off-line	1D	2D	3D	Single	Multi.	Orientation	Orientation	Fragility	Precedence	Stability	Total Conflicts	Partial conflicts
1	[102]	SBSBPP		x			x	x		x			x	x	x	
2	[84]	MBSBPP		x	x			x							x	
3	[260]	SBSBPP		x		x		x								
4	[121]	SBSBPP		x			x	x		x						
5	[14]	SBSBPP	x			x		x								
6	[103]	MBSBPP		x		x		x		x	x					
7	[2]	SBSBPP		x	x			x								
8	[45]*	SBSBPP		x	x			x								
9	[123]	SBSBPP		x		x			x							
10	[95]	SBSBPP		x			x		x	x				x		
11	[34]	SBSBPP		x	x			x								
12	[250]	SBSBPP		x		x		x								
13	[167]	MBSBPP		x	x			x								
14	[235]	SBSBPP		x				x								
15	[258]	MBSBPP		x	x			x								
16	[11]	MBSBPP		x	x			x								
17	[216]	SBSBPP		x	x				x							
18	[125]	SBSBPP		x		x		x			x					
19	[97]	SBSBPP		x		x		x								
20	[221]	ODP		x		x		x								
21	[143]	SBSBPP	x			x		x								
22	[114]	SBSBPP		x			x	x					x	x		
23	[171]	SBSBPP		x	x			x							x	
24	[15]	SBSBPP	x		x			x								
25	[159]	SBSBPP		x	x			x						x	x	
26	[108]	MBSBPP	x		x			x							x	
27	[217]	SBSBPP		x		x		x		x						
28	[157]	SBSBPP		x	x			x								
29	[1]	SBSBPP		x	x			x								
30	[273]	SBSBPP		x			x	x								
31	[205]	MBSBPP		x			x	x		x		x		x		
32	[62]	SBSBPP		x		x		x		x						
33	[90]	MBSBPP		x	x			x								
34	[51]*	SBSBPP and ODP	x	x	x	x		x		x	x					
35	[172]	SBSBPP		x		x		x			x					
36	[263]	SBSBPP		x		x		x		x	x		x			

Table 7 (continued)

No.	paper	Problem type	Data		Dimensionality			Objective		Constraints						
		Rectangular Shape	On-line	Off-line	1D	2D	3D	Single	Multi.	Orientation	Orientation	Fragility	Precedence	Stability	Total Conflicts	Partial conflicts
37	[86]	SBSBPP		x			x	x						x		
38	[191]	MBSBPP		x	x			x								
39	[71]	SBSBPP		x		x		x								
40	[7]	SBSBPP		x		x		x								
41	[182]	SBSBPP		x			x	x		x						
42	[206]	SBSBPP		x			x	x		x		x		x		
43	[8]	SBSBPP		x	x			x								
44	[9]	SBSBPP	x		x			x								
45	[38]	SBSBPP		x	x	x		x								
46	[33]*	SBSBPP and MSBPP		x		x	x	x	x		x					
47	[64]	MBSBPP	x		x			x								
48	[68]	SBSBPP		x		x		x			x					
49	[111]	SBSBPP		x	x			x								
50	[138]	MBSBPP		x			x	x		x						
51	[139]	SBSBPP		x	x			x								
52	[197]	SBSBPP		x		x		x								
53	[198]	SBSBPP		x			x	x				x	x	x		
54	[202]*	ODP		x		x		x		x	x					
55	[166]	SBSBPP		x			x	x		x			x			
56	[269]	ODP		x		x		x		x	x					
57	[245]	MBSBPP		x			x	x		x			x			
58	[246]	MBSBPP		x			x	x		x						
59	[270]	SBSBPP	x			x		x		x						
60	[271]	SBSBPP		x	x			x								
61	[25]	SBSBPP		x		x		x							x	
62	[30]	SBSBPP		x		x		x		x						
63	[32]	SBSBPP		x	x			x							x	
64	[41]	SBSBPP		x	x			x								
65	[54]	SBSBPP		x	x			x					x			
66	[69]	SBSBPP		x		x		x		x	x					
67	[70]	SBSBPP		x		x		x								
68	[78]	SBSBPP		x	x			x					x			
69	[80]*	SBSBPP		x	x			x								
70	[101]	MBSBPP		x	x			x								
		MBSBPP		x	x			x							x	
71	[247]	MBSBPP		x	x			x								
72	[132]	SBSBPP		x		x		x								
73	[144]	SBSBPP		x	x			x								
74	[210]	SBSBPP		x	x			x					x			
75	[211]	SBSBPP		x	x			x								
76	[231]	MBSBPP		x			x	x		x						
77	[50]	SBSBPP		x	x			x								
78	[251]	SBSBPP		x		x		x		x						
		ODP		x		x		x		x						
79	[255]	SBSBPP		x		x		x								
80	[13]	MBSBPP		x		x		x								
81	[49]	SBSBPP		x		x		x								
82	[262]	MBSBPP		x			x	x		x						
83	[117]	SBSBPP		x		x			x							x
84	[57]	SBSBPP		x	x			x				x				
85	[63]	SBSBPP		x		x		x		x			x			
86	[88]	MBSBPP		x	x			x					x			
87	[122]	SBSBPP		x	x			x								
88	[165]	SBSBPP		x		x		x		x					x	
89	[127]	MBSBPP		x		x		x			x					
90	[180]	MBSBPP		x	x	x		x								
91	[200]	SBSBPP		x	x				x				x			
92	[220]	SBSBPP		x	x			x								
93	[238]	SBSBPP		x		x		x								
94	[249]	SBSBPP		x			x	x		x	x					
95	[266]	SBSBPP		x	x			x							x	
96	[264]	SBSBPP	x		x			x								
97	[242]	SBSBPP		x	x			x								
98	[141]	SBSBPP		x		x		x					x			x
99	[6]	MBSBPP		x		x	x	x								
100	[256]	SBSBPP and MBSBPP		x	x	x		x								
101	[27]	SBSBPP		x		x			x	x			x			
102	[31]	SBSBPP		x		x		x								
103	[35]	SBSBPP		x			x			x		x	x			
104	[42]	SBSBPP		x			x			x		x	x			
105	[47]	SBSBPP		x		x	x	x								
106	[81]	ODP		x		x		x		x			x			
107	[96]	SBSBPP		x		x		x	x	x						

Table 7 (continued)

No.	paper	Problem type	Data		Dimensionality			Objective		Constraints						
		Rectangular Shape	On-line	Off-line	1D	2D	3D	Single	Multi.	Orientation	Orientation	Fragility	Precedence	Stability	Total Conflicts	Partial conflicts
108	[98]	SBSBPP		x		x		x		x	x					
109	[204]	SBSBPP		x			x	x							x	
110	[140]	SBSBPP		x	x			x								
111	[183]	MBSBPP		x	x			x								
112	[192]	SBSBPP		x		x			x						x	
113	[193]	MBSBPP		x			x	x								
114	[209]	SBSBPP		x	x			x								
115	[223]	SBSBPP		x	x			x					x			
116	[230]	SBSBPP		x	x			x							x	
117	[156]	SBSBPP		x	x			x								
118	[12]	SBSBPP		x	x			x								
119	[53]	MBSBPP		x		x		x		x	x					
120	[79]	SBSBPP		x	x			x					x			
121	[181]	SBSBPP		x		x	x	x		x	x					
122	[151]	SBSBPP		x	x			x	x						x	
123	[152]	SBSBPP		x		x		x							x	
124	[20]	SBSBPP		x		x		x								
125	[213]	SBSBPP		x		x		x								
126	[161]	SBSBPP		x		x		x			x					
127	[124]	MBSBPP		x	x			x								
128	[252]	SBSBPP		x		x		x								
129	[272]	SBSBPP		x		x	x	x								
130	[147]	SBSBPP		x			x	x		x						
131	[194]	MBSBPP		x			x	x								
132	[265]	SBSBPP		x	x			x								
133	[160]	SBSBPP		x	x			x								
134	[118]	SBSBPP		x		x		x								x
135	[212]	SBSBPP		x	x			x								
136	[18]	SBSBPP and MBSBPP		x	x			x								
137	[224]	SBSBPP		x	x			x								
138	[142]	SBSBPP		x			x	x				x		x		
139	[233]	ODP and SBSBPP		x		x		x		x						
140	[162]	SBSBPP		x		x		x					x			
141	[46]	SBSBPP		x		x		x		x	x					
142	[169]	SBSBPP		x		x		x		x	x					
143	[195]	MBSBPP		x			x	x								
144	[184]	SBSBPP		x	x			x							x	
145	[119]	MBSBPP		x	x			x								
146	[164]	SBSBPP		x			x	x		x		x		x		
147	[225]	SBSBPP		x	x			x		x			x			
148	[268]	SBSBPP		x		x	x	x								
149	[257]	ODP and SBSBPP		x		x		x		x						
150	[93]	MBSBPP	x		x			x							x	
151	[100]	SBSBPP		x			x	x		x		x	x	x		
152	[16]	SBSBPP	x			x		x								
153	[5]	SBSBPP		x			x	x					x			
154	[203]	ODP and MBSBPP		x		x		x		x						
155	[66]	MBSBPP		x	x			x								
156	[126]	SBSBPP		x			x	x								
157	[208]			x		x	x	x								
158	[237]	SBSBPP		x		x		x								
159	[145]	ODP and SBSBPP		x		x		x			x					
160	[196]	ODP		x		x			x		x					
161	[153]	SBSBPP		x	x			x	x						x	
162	[199]	SBSBPP		x	x			x							x	
163	[259]	SBSBPP		x		x		x		x						
164	[218]	SBSBPP		x		x		x		x	x					
165	[227]*	ODP		x		x		x		x	x					
166	[110]	SBSBPP		x	x			x								
167	[4]			x	x				x						x	
168	[10]	ODP		x		x		x					x			
169	[120]	MBSBPP		x	x			x								
170	[134]	ODP		x		x			x	x						
171	[185]	SBSBPP		x	x			x							x	
172	[201]	ODP		x		x		x			x					
173	[232]	SBSBPP		x	x				x							
174	[261]	SBSBPP and MBSBPP		x			x	x		x						
175	[19]	SBSBPP		x	x			x				x				
176	[24]	ODP		x		x		x								
177	[55]	SBSBPP		x		x		x								
178	[67]	SBSBPP		x		x	x	x								
179	[85]	SBSBPP		x		x		x		x						
180	[105]	SBSBPP		x	x				x							

Table 7 (continued)

No.	paper	Problem type	Data		Dimensionality			Objective		Constraints						
		Rectangular Shape	On-line	Off-line	1D	2D	3D	Single	Multi.	Orientation	Orientation	Fragility	Precedence	Stability	Total Conflicts	Partial conflicts
181	[112]	SBSBPP		x			x	x							x	
182	[170]	SBSBPP		x		x			x							
183	[187]	SBSBPP		x		x		x					x	x		
184	[234]	SBSBPP		x	x			x					x			
185	[48]	ODP		x		x		x		x						
186	[56]	SBSBPP		x		x		x								
187	[94]	SBSBPP	x	x	x			x							x	
188	[135]	ODP		x		x			x							
189	[214]	SBSBPP		x		x		x			x			x		
190	[115]	ODP		x		x		x								
191	[219]	SBSBPP		x		x		x								
192	[44]	SBSBPP	x		x			x				x				
193	[23]	MBSBPP		x		x		x								
194	[36]	ODP		x		x		x		x	x					
195	[226]	SBSBPP		x		x		x								
196	[240]	SBSBPP		x		x		x								
197	[21]	SBSBPP		x		x		x			x					
198	[22]	SBSBPP		x	x			x							x	
199	[136]	SBSBPP		x		x		x								
200	[215]	MBSBPP		x		x		x								
201	[106]	SBSBPP		x	x			x							x	
202	[244]	SBSBPP		x	x			x								
203	[173]	ODP and SBSBPP		x		x		x		x						
204	[77]	SBSBPP		x			x	x						x		
205	[137]	SBSBPP		x		x		x		x						
206	[148]	MBSBPP		x	x			x								
207	[254]	SBSBPP		x		x			x							
208	[163]	SBSBPP		x		x		x								
209	[188]	ODP		x		x		x								
210	[158]	SBSBPP		x	x			x								
211	[228]	SBSBPP		x	x			x								
212	[37]	SBSBPP		x		x		x								
213	[40]	SBSBPP		x		x		x								
214	[174]	SBSBPP		x		x		x								
215	[176]	SBSBPP		x			x	x								
216	[175]*	SBSBPP		x		x		x		x	x					
217	[155]	SBSBPP		x	x			x								
218	[248]*	SBSBPP		x	x			x								
219	[229]	SBSBPP		x	x			x								
220	[76]	MBSBPP		x	x			x								
221	[128]	SBSBPP		x		x		x		x						
222	[150]	SBSBPP		x		x		x		x						
223	[244]	SBSBPP		x			x	x		x		x		x		
224	[39]	ODP		x		x		x								
225	[113]	SBSBPP		x	x			x								
226	[129]	SBSBPP		x		x		x		x						
227	[178]	SBSBPP		x		x		x		x	x					
228	[177]	SBSBPP		x		x		x								
229	[236]	SBSBPP		x	x			x								
230	[130]*	SBSBPP		x		x	x	x			x					
231	[267]	MBSBPP	x		x			x								
232	[17]	SBSBPP	x		x			x								
233	[241]	SBSBPP		x		x		x		x						
234	[116]	MBSBPP		x		x		x								
235	[133]	ODP and SBSBPP		x		x		x		x						
236	[189]	SBSBPP		x	x			x								
237	[154]	MBSBPP	x		x			x								
238	[29]	ODP		x		x		x								
239	[99]	MBSBPP		x	x			x								
240	[82]*	SBSBPP		x		x	x	x		x	x					
241	[52]	SBSBPP		x		x		x								
242	[26]	ODP and SBSBPP		x		x		x		x						
243	[109]	ODP		x		x		x								
244	[59]	ODP		x		x		x								
245	[107]	SBSBPP		x			x	x					x			
246	[60]	SBSBPP	x		x			x								

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