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E DELL'INFORMAZIONE

Executive Summary of the Thesis

Three-dimensional bin packing with vertical support

Laurea Magistrale in Computer Science and Engineering - Ingegneria Informatica

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1. Introduction

Recent progress in the digitalization of industrial processes led to a rise in studies on the Three-Dimensional Bin Packing Problem (3D-BPP). The problem consists in packing a set of items in the minimum number of bins without any overlap. When considering real-world settings, the addition of new practical constraints is required. Previous studies in other fields related to container loading and pallet loading have shown that static stability of the bins is a crucial aspect to consider (Bortfeldt and Wäscher [2013]). In this thesis, we address a version of the bin packing problem stemming from a real case study of mixed-case palletization: the Three-Dimensional Bin Packing Problem with Vertical Support (3D-BPPVS). We extend the standard formulation of the bin packing problem by ensuring that all items that are packed inside a bin will not fall, and we refer to this property as the vertical support.

Our research stems from the case study of a logistics company in northern Italy. The company manages large warehouses where automated lines bring boxes to different packing stations, and then they are loaded onto pallets of standard size. Since the company is dealing directly with customers' orders, boxes have very different sizes and are usually packed in smaller quantities. Moreover, the assortment of items to pack is strongly heterogeneous which makes the use of layered approaches to have sub-optimal results. During the palletization, the lower levels of already packed items are wrapped to ensure better overall stability of the pallet. This wrapping procedure requires that the ammount of unused space between items is minimal and measures this property with a metric called cage ratio. Cage Ratio is the ratio between the volume of the packed items inside a bin and the volume of the cuboid which surrounds them called cage. The cage has the same base as the bin and the height equalt to the heighest packed item inside the bin. Current commercial solutions employed by the company have solutions with around 60% cage ratio, and a target of 70% was set as a benchmark for our work.

Since the 3D-BPP is the generalization of the one-dimensional bin packing problem, it is NP-Hard (Martello et al. [2000]). Exact methods can only solve small instances of the problem which means that most solutions proposed in the literature are heuristics. The concept of vertical support received most of its contribution from the literature of Container Loading Problems (CLP) and Pallet Loading Problems (PLP). As noted in Bortfeldt and Wäscher [2013], static

stability is usually implicitly enforced as a consequence of load compactness, or explicitly guaranteed by using filler material in a postprocessing step. Most heuristics for CLPS and PLPs try to build dense layers composed of similar items that they then stack, reducing the problem to a one-dimensional bin packing problem. Layers are filtered based on the fill-rate and when they are below a certain threshold they are discarded (e.g., Alonso et al. [2020]; Elhedhli et al. [2019]). This means that when no new layer can be built, new bins are opened, simpler placement methods are used to pack the remaining items or filler material is used to complete the layers.
Our solution to the problem fills the gap in the research by finding solutions to the 3D-BPPVS without explicitly building layers, and without the use of filler material.

2. Proposed Solution

3. Computational Experiments and Results

4. Conclusions and Future Developments

5. Guidelines

The Executive Summary is a critical overview of your thesis with a focus on the main achievements that have emerged from your research.
The Executive Summary should be organized in sections/paragraphs in order to better highlight the major points of your work. The length should range from four to six pages depending on the length of the thesis manuscript. Keep the Executive Summary concise enough to be effective but long enough to allow it to be complete. It should be written after completing the thesis manuscript as a stand-alone independent document of sufficient clarity and detail to ensure that the reader can figure out the overall objectives, the methodology employed and the results/impact of your research.
In writing the Executive Summary, keep in mind that it is not an abstract, it is not a preface, and it is not a random collection of highlights. With a few exceptions, do not simply cut and paste whole sections or paragraphs of the thesis manuscript into a disorganized and cluttered Executive Summary. You should reorganize information to be informative as well as concise.
The Executive Summary could contain a few important equations related to your work. It could also include the most relevant figures and tables taken or elaborated from the thesis manuscript. You should also include in the Executive Summary the very essential bibliography of your study. The number of selected references should range from three to five depending on the type of work.
The Executive Summary should contain a final section reporting the main conclusions drawn from your research.
Allen et al. [2011]

6. Sections and subsections

It is convenient to organize the Executive Summary of your thesis into sections and subsections. If necessary, subsubsections, paragraphs and subparagraphs can be also used. A new section or subsection can be included with the commands

```
\section{Title of the section}

\subsection{Title of the subsection}
```

It is recommended to give a label to each section by using the command

```
\label{sec:section_name}%
```

where the argument is just a text string that you'll use to reference that part as follows: *Section 6 contains* SECTIONS AND SUBSECTIONS ....

7. Equations, Figures, Tables and Algorithms

All Figures, Tables and Algorithms have to be properly referred in the text. Equations have to be numbered only if they are referred in the text.

7.1. Equations

A few important equations related to your work might be reported in the Executive Summary.

For example, the Maxwell's equations read:

$$\begin{cases} \nabla \cdot \boldsymbol{D} = \rho, & \text{(1a)} \\ \nabla \times \boldsymbol{E} + \dfrac{\partial \boldsymbol{B}}{\partial t} = \boldsymbol{0}, & \text{(1b)} \\ \nabla \cdot \boldsymbol{B} = 0, & \text{(1c)} \\ \nabla \times \boldsymbol{H} - \dfrac{\partial \boldsymbol{D}}{\partial t} = \boldsymbol{J}. & \text{(1d)} \end{cases}$$

Equation (1) is automatically labeled by `cleveref`, as well as Equation (1a) and Equation (1c). Thanks to the `cleveref` package, there is no need to use `\eqref`.

7.2. Figures

To include Figures in your text you can use `TikZ` for high-quality hand-made figures, or just include them with the command

`\includegraphics[options]{filename.xxx}`

where xxx is the format (`.png`, `.jpg`, `.eps`, ...). An example is shown in Figure 1.

Figure 1: Caption of the Figure.

7.3. Tables

Within the environments `table` and `tabular` you can create very fancy tables like the one shown in Table 1.

Example of Table

	column1	column2	column3
row1	1	2	3
row2	α	β	γ
row3	alpha	beta	gamma

Table 1: Caption of the Table.

7.4. Algorithms

Pseudo-algorithms can be written in LaTeX with the `algorithm` and `algorithmic` packages. One example follows.

Algorithm 1 Name of the Algorithm

```
Initial instructions
for for − condition do
    Some instructions
    if if − condition then
        Some other instructions
    end if
end for
while while − condition do
    Some further instructions
end while
Final instructions
```

8. Some further useful recommendations

Theorems and Propositions have to be formatted as follows:

Theorem 8.1. *Write here your theorem.*

Proof. If useful you can report here the proof.

How to write propositions:

Proposition 8.1. *Write here your proposition.*

How to insert itemized lists:

- first item;
- second item.

How to insert numbered lists:

1. first item;
2. second item.

9. Bibliography

The Executive Summary should contain the very essential bibliography of your study. It is suggested to use the BibTeX package and save the bibliographic references in the file `literature.bib`.

10. Conclusions

A final section containing the main conclusions of your research/study have to be inserted here.

11. Acknowledgements

Here you might want to acknowledge someone.

References

[1] Allen, S., Burke, E., and Kendall, G. (2011). A hybrid placement strategy for the three-dimensional strip packing problem. *European Journal of Operational Research*, 209(3):219–227.

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[4] Elhedhli, S., Gzara, F., and Yildiz, B. (2019). Three-dimensional bin packing and mixed-case palletization. *INFORMS Journal on Optimization*, 1(4):323–352.

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