20th ESICUP Meeting

Guimarães, Portugal, April 17-19, 2024

Organization

EURO THE ASSOCIATION OF EUROPEAN OPERATIONAL RESEARCH SOCIETIES

University of Minho
School of Engineering

EWG ESICUP CUTTING AND PACKING

CENTROALGORITMI
http://algoritmi.uminho.pt

LASI Intelligent Systems Associate Laboratory

MUNICÍPIO DE GUIMARÃES

Table of Contents

Thanks are given to many sponsors, who made possible the realization of this event.

ESICUP: Working Group on Cutting and Packing within EURO, the Association of the European Operational Research Societies

University of Minho: School of Engineering of the University of Minho

Município de Guimarães: Guimarães City Council

Centro ALGORTIMI: Centro ALGORITMI is a research unit of the School of Engineering – University of Minho

LASI: Intelligent Systems Associate Laboratory

Welcome

Dear Friends, Welcome to the 20th Meeting of ESICUP - The EURO Special Interest Group on Cutting and Packing. Since its formal recognition as a EURO Working Group in 2003, ESICUP has run a series of annual meetings, which have successfully brought together researchers and practitioners in the field of cutting and packing. Previous meetings have been organised across Europe with occasional meetings further afield including Tokyo (Japan), Buenos Aires (Argentina), Beijing (China), Mexico City (México). After the last successful edition in Bologna, Italy, the 20th Meeting of ESICUP will be held in Guimarães, Portugal.

Once again, this meeting will serve as an instrument for the development of research and the dissemination of knowledge in our field. From the scientific viewpoint, there will be thirty-two presentations, that cover many problems and aspects in the Cutting and Packing area, thus allowing for clear insights into the current state-of-the-art for this class of problems and preparing the ground for fruitful discussions.

We are celebrating the 20th edition of ESICUP. On this occasion, we invited the distinguished plenary speaker José Fernando Oliveira to talk about the history of ESICUP.

Founded in 1973, the University of Minho welcomed its first students in the academic year of 1975/76. At present, the University is renowned for its competence and quality of teaching staff, excellence in scientific research, wide range of undergraduate and graduate courses offered and for its high level of interaction with other institutions. For these reasons, UMinho has a central role in the region and is an important reference for the country and a recognised partner in the European and global scene. Located in the north of Portugal, the University has a campus in Braga and two in Guimarães, Azurém Campus and Couros Campus.

Guimarães is a historical city in northwestern Portugal, around 350 km north of the capital city, Lisbon, and 50 km from the second-largest city, Porto. It has a population of around 160,000 inhabitants and is located in one of the most industrialized sub-regions in the country.

Guimarães played a crucial role in the foundation of Portugal as a country in the 12th century, earning the nickname of 'Cradle-City'. It has a rich history spanning more than a millennium since its founding, when it was known as Vimaranes.

In 2001, UNESCO recognized the city centre as a Cultural Heritage of Humanity, making it one of the biggest tourism centres in the region. The streets and monuments in Guimarães are full of history and charm, attracting visitors from all over the world. In 2023, the Cultural Heritage of Humanity recognition was extended to the industrial remains of its leather factories (Zona de Couros).

Despite its historical significance, Guimarães has managed to balance heritage conservation with contemporary city dynamics and entrepreneurship, making it a unique and vibrant city.

Finally, we would like to express our sincere thanks to the members of both the Program Committee and the Organizing Committee, whose enthusiasm and effort were crucial for having this meeting. We wish all of you a successful conference and a very pleasant stay in Guimarães!

Thank you to the organising committee and the ESICUP co-ordinating committee for their time in making this meeting happen. Tony Wauters, Elsa Silva, José Valério de Carvalho

Tony Wauters
KU Leuven
Program Chair

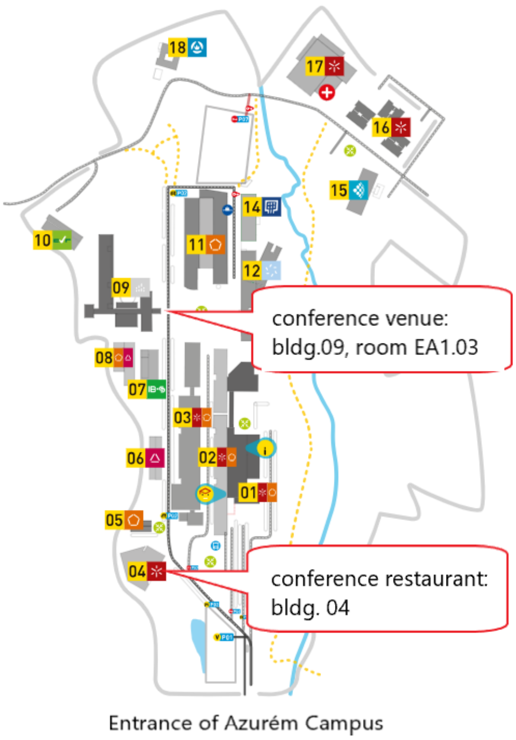
Elsa Silva
University of Minho
Organizer

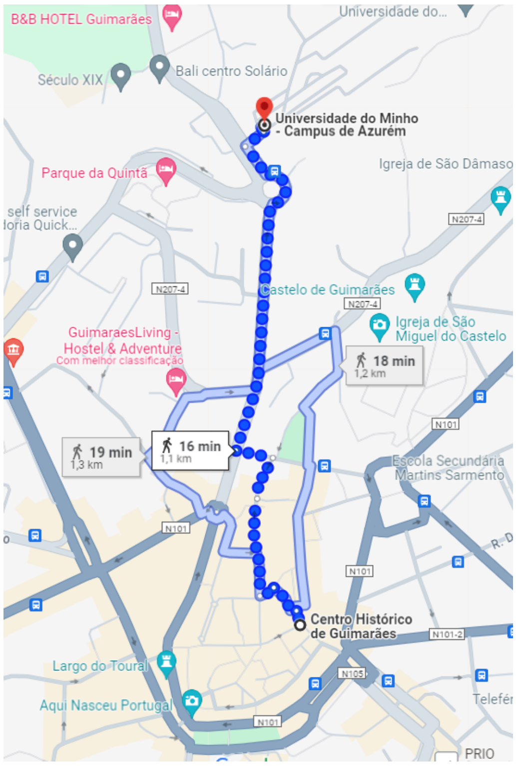
José Valério de Carvalho
University of Minho
Organizer

Information for Conference Participants

Conference Venue

The conference venue is Room EA1.03 of the School of Architecture (building 09), Campus de Azurém. `https://whereis.uminho.pt/CA.html`





Address

Campus de Azurém, Av. da Universidade, 4800-058 Guimarães

How to get to Campus de Azurém

The Campus is within a walking distance (a 16-minute walk from the historic center of Guimarães), see picture above).

Nearest bus stop

'Universidade', served by bus lines:

- 003 LINHA CIDADE (VIA AZURÉM E MADRE DEUS)

- 004 LINHA CIDADE (VIA TOURAL E EB23 JOÃO MEIRA)

- 032 CIRCULAR AZURÉM-PEDROSO

check schedules at: `https://guimabus.pt/horarios-linhas/#1671136565889-7eac2e76-efad`

From the airport/station

How to get to Guimarães from the Porto airport:

- Shuttle bus (Get Bus), see `https://www.getbus.eu/en/guimaraes-porto-airport`

- Metro: Porto airport - Porto Train Station, see `https://en.metrodoporto.pt/`

- Train: Porto Train Station - Guimarães Train Station (Estação CP Guimarães), see https://www.cp.pt/passageiros/en

Moving Inside Guimarães

- Guimarães Train Station (Estação CP Guimarães) - Campus de Azurém (bus stop: Universidade): use bus line: 004 LINHA CIDADE (VIA TOURAL E EB23 JOÃO MEIRA)

- Guimarães Bus Station (Central de Camionagem - Alameda) - Campus de Azurém (bus stop: Universidade): use bus line: 004 LINHA CIDADE (VIA TOURAL E EB23 JOÃO MEIRA)

check schedules at: https://guimabus.pt/horarios-linhas/#1671136565889-7eac2e76-efad

Get-together Evening

Welcome on Wednesday will be in Casa Amarela at 8 pm.

Casa Amarela
Largo de Donães 24, 4800-408 Guimarães
https://maps.app.goo.gl/t9yRkTncaqXGVDET7

Conference dinner

The Conference dinner will be in Restaurante Café Oriental.

Restaurante Café Oriental
Largo do Toural 11, 4810-427 Guimarães
https://maps.app.goo.gl/b7TKjJMVXdCEWf6x5

Registration

The registration desk will be located in the meeting venue where you will collect your name badge and registration pack for the event.

Your name badge

You should wear your name badge at all times during the event. It is your admission to the venue (includes coffee breaks and lunch).

Equipment

The conference room is equipped with an overhead projector, a video projector and a computer.

We suggest that you bring your own computer and/or transparencies as a backup.

Length of Presentation

18 minutes for each talk, including discussion. Please note that we are running on a very tight schedule.

Therefore, it is essential that you limit your presentation to the time which has been assigned to you.

Session chairpersons are asked to ensure that speakers observe the time limits.

Internet Access

University of Minho provides Wi-Fi access to the eduroam network. The following credentials can be used to assess the eduroam network.
Username: esicup@guest
Password: esicup24

In case of difficulty, check the instructions at the appendix of this booklet.

Dietary, Mobility and Other Requirements
Please let the registration desk know if you have any additional special requirements.

Program Overview

	Wednesday 17/04/2024	Thursday 18/04/2024	Friday 19/04/2024
8:45		Registration	
9:15		Opening Session	Session 5 (4 talks)
9:30		Session 1 (5 talks)	
10:30			Coffee Break
11:00		Coffee Break	Session 6 (5 talks)
11:30		Plenary talk: José Fernando Oliveira	
12:30		Lunch Break	Lunch Break
14:00		Session 2 (5 talks)	Session 7 (5 talks)
15:30		Coffee Break	Closing Session
16:00		Session 3 (4 talks)	Tour of Guimarães
17:15		Short break	
17:30		Session 4 (4 talks)	
18:45			
20:00	Get Together	Conference Dinner	
21:00			

Scientific Program Schedule

Thursday

9:20 – 9:30

Opening Session *Elsa Silva and Valério Carvalho*

9:30 – 11:00

Session 1 *Chair: Julia Bennell*

1.1 – Packing Soft Polygons in an Optimized Convex Container
Tetyana Romanova, Igor Litvinche, Alexander Pankrato, Julia Bennell, Melashenko Oksana

1.2 – Decoupling Geometry from Optimization: an Open-Source Collision Detection Engine for 2D irregular Cutting and Packing problems
Jeroen Gardeyn, Greet Vanden Berghe, Tony Wauters

1.3 – Applying Zero-Waste Design Principles: Case Studies on Pattern Manipulation Strategies for Cutting and Packing Optimisation
Nesma ElShishtawy, Julia Bennell, Pammi Sinha

1.4 – Models and optimization methods for solving irregular packing and covering problems
Sergiy Yakovlev, Oleksii Kartashov, Dmytro Podzeha, Iryna Yakovleva

1.5 – Solving Nesting Problems with Guillotine Cuts: A Novel Branch-and-Cut Algorithm
Luiz Henrique Cherri, Adriana Cristina Cherri, Everton Fernandes Silva, José Fernando Oliveira

11:30 – 12:30

PLENARY TALK *Chair: Tony Wauters*

– Paris - Guimarães: Cutting and Packing around the world in 36 years
José Fernando Oliveira

14:00 – 15:30

Session 2 *Chair: Marta Cabo Nodar*

2.1 – Two-Dimensional Packing for Task Scheduling in High-Performance Computing
Enrico Malaguti, Michele Monaci, Antonio Punzo

2.2 – Mathematical programming for the 2D cutting stock problem with variable sized stock applied to the honeycomb cardboard industry.
Paula Terán-Viadero, Antonio Alonso-Ayuso, F. Javier Martín-Campo

2.3 – A 2D Bin Packing Problem in the Sheet Metal Industry: Models and Solution Approaches
Luigi De Giovanni, Nicola Gastaldon, Chiara Turbian

2.4 – A new exact, graph-based approach for the Two-Dimensional Knapsack Problem with Obstacles
Alessio La Greca, Giovanni Righini

2.5 – Beam Search to Minimise Cutting Patterns with Maximum Utilisation
Marta Cabo Nodar, Claudia O. López Soto

16:00 – 17:15

Session 3 *Chair: Francisco Parreño*

3.1 – The optimal container selection problem for parts transportation in the automotive sector
Marta Cildoz, Pedro M. Mateo, Maria Teresa Alonso, Francisco Parreño, Ramon Alvarez-Valdes, Fermin Mallor

3.2 – Math-heuristic Approach for Truck Packing with Delivery Deadlines: Roadef 2022 Challenge
Francisco Parreño, María Teresa Alonso, Ramón Álvarez-Valdés

3.3 – A load balance methodology for multi-compartment tank-truck loading problem in road fuel transportation
Ângelo Soares, Roberto Paixão, António G. Ramos, Elsa Silva

3.4 – Heuristics for industrial online three-dimensional packing problems
Sara Ali, António Galrão Ramos, José Fernando Oliveira

17:30 – 18:45

Session 4 *Chair: Ramon Alvarez-Valdes*

4.1 – The diamond cutting problem
Jonas Tollenaere, Tony Wauters

4.2 – 3D Irregular Cutting and Packing for the Nuclear Waste from Tokamak Fusion Reactor
Yifu Wei, Julia Bennell, Hamish Carr, and Tatiana Romanova

4.3 – Algorithm for On-Line Irregular 3D Packing
Pedro Rocha , António Ramos , Elsa Silva

4.4 – Simulation of 3D volume filling with non-spherical and sperical titanium alloy powder particles for additive manufacturing
Alexander Pankratov, Yuri Stoyan, Tetyana Romanova, Igor Lemishk, Zoia Duriagina

Friday

9:15 – 10:30

Session 5 *Chair: Paquay Célia*

5.1 – Robust Bin Packing Problem with Fragility Constraints
Heloisa Vasques da Silva, Alberto Locatelli, Silvio Alexandre de Araujo, Manuel Iori

5.2 – Column generation for cutting stock problem with usable leftovers in industrial joinery
Victor Senergues, Nadjib Brahimi, Olivier Peton

5.3 – Mathematical formulations for wood recycling optimization
Bessemans Pauline, Paquay Célia

5.4 – Bounding Procedures and Exact Arcflow Formulations for the Bin Packing Problem with Minimum Color Fragmentation
Mathijs Barkel, Maxence Delorme, Enrico Malaguti, Michele Monaci

11:00 – 12:30

Session 6 *Chair: Schyns Michaël*

6.1 – A Deep Reinforcement Learning Approach for the 3D multiple bin packing problem
Evers Justine and Schyns Michaël

6.2 – Solving the two dimensional strip packing problem using reinforcement learning framework
Fatih Burak Akçay, Maxence Delorme

6.3 – Enhancing Last-Mile Delivery Efficiency through Geospatial Clustering and District Optimization
Farzam Salimi, António Galrão Ramos

6.4 – A multi-start metaheuristic for solving the problem of slitting steel plate coils
Óscar Soto-Sánchez, María Sierra-Paradinas, Micael Gallego and Antonio Alonso-Ayuso

6.5 – Sustainability of cutting and packing problems: beyond waste minimization
Matheus Campinho, Elsa Silva, José Fernando Oliveira, Maria Antónia Carravilla

14:00 – 15:30

Session 7 *Chair: António G. Ramos*

7.1 – A new construction heuristic for an online three-dimensional packing problem: a case study
Burcu Özbel, António G. Ramos, Pedro Rocha

7.2 – A column-generation matheuristic approach for optimizing a 3-stage Packing Problem
Khadija Hadj Salem, Benoit Lardeux, Xavier Schepler

7.3 – Optimizing Manufacturer's Pallet Loading: Balancing Stability and Efficiency
Joao Araujo, Antonio G. Ramos, Elsa Silva

7.4 – Matheuristic approaches to binding the routing and cargo load balance problems
Elsa Silva, António G. Ramos, Ana Moura

7.5 – The Pallet Loading Problem on a Robotic Loader System
Davide Croci, Ola Jabali, Federico Malucelli, Joe Naoum-Sawaya

15:30 – 15:45

Closing Session *Tony Wauters*

Social Program

- **Welcome - Wednesday 17th of April**

  The Get-together Welcome is hosted at Casa Amarela, Largo de Donães, 24, 4800-408 Guimarães
  `https://casaamarela.pt/`
  `https://maps.app.goo.gl/t9yRkTncaqXGVDET7`

  Begins at 8 PM
  Badges will be delivered, and a registration desk will be available.

- **Thursday 18th of April**

  The Social dinner will be hosted at Restaurante Oriental, Largo do Toural 11, 4810-427 Guimarães
  `https://restaurantecafeoriental.com/`.
  `https://maps.app.goo.gl/b7TKjJMVXdCEWf6x5`

  Meeting time 8 PM

- **Friday 19th of April**

  The Tour of Guimarães is planned at 4 pm.
  Meeting point: statue of D. Afonso Henriques (first king of Portugal), in front of Paço dos Duques.
  `https://maps.app.goo.gl/YF8MHFdmfy5ZFLoW8`
  After the closing session, we will walk to the meeting point.

Abstracts

Plenary Talk

Paris - Guimarães: Cutting and Packing around the world in 36 years

José Fernando Oliveira[‡]

[‡] *INESC TEC, Faculty of Engineering, University of Porto, Portugal*

During EURO IX/TIMS XXVIII in Paris, 5–8 July 1988, a stream on Cutting and Packing Problems was organised by Gerhard Wäscher and Harald Dyckhoff. In the final session of the stream, they proposed to all the participants the formation of a Special Interest Group on Cutting and Packing, which was enthusiastically accepted by all the researchers present. It was also decided that the group would meet every other year so that interesting new work could be developed between meetings. Many years later, Gerhard confessed that Harald and he were convinced that there would be room for ten years of active research in the field. After that, research opportunities would be scarce and would no longer justify the existence of an interest group. Fortunately, Gerhard was wrong this time, and 36 years later, after meetings all over the world, from Tokyo to Buenos Aires, we are here in Guimarães, in a lively meeting, with many young people with new ideas, tackling sophisticated and challenging cutting and packing problems. In this talk I will try to connect the dots between Paris and Guimarães.

Keywords: Cutting and packing, Plenary.

1.1

Packing Soft Polygons in an Optimized Convex Container

Tetyana Romanova[*],[†], Igor Litvinchev[‡], Alexander Pankratov[†], Julia Bennell[*], Melashenko Oksana[†]

[*] *University of Leeds, Maurice Keyworth Building, Leeds, LS2 9JT, UK, T.Romanova@leeds.ac.uk, J.Bennell@leeds.ac.uk*

[†] *A. Pidhornyi Institute of Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, 2/10 Pozharskogo st., Kharkiv 61046, Ukraine, pankratov2001@yahoo.com*

[‡]*Nuevo Leon State University (UANL), Monterrey, Av. Universidad s/n, Col. Ciudad Universitaria, San Nicolas de los Garza, Nuevo Leon, CP 66455, Mexico; igorlitvinchev@gmail.com*

In 2D packing problems several objects must be placed in a container without overlapping while optimizing a metric characteristic of the container, e.g., its dimension or area. Although the objects can be freely translated and rotated, the shapes of the objects typically are assumed to be fixed and cannot be changed during the packing process. That is, the objects are considered rigid. Optimized packing rigid objects is well studied and has various applications. However, in many cases the objects can change their shapes under certain restrictions, i.e., the problem of packing soft objects (objects with variable shape) arises. The most frequently used restriction is the area conservation for each soft object. Packing soft objects has various applications, e.g., in biology, mechanics and material science. In particular, packing soft rectangles one can find in floor planning, land allocation and logistics. Interesting application of this class of packing problems is motivated by studying properties of porous media under external force. A nonstandard optimized packing convex polygons in a convex polygonal container is considered. The shapes of the polygons are not fixed: the polygons can be compressed/stretched in certain limits, but the object remains convex and maintains its area unchanged under all shape transformations. The polygons must be placed completely inside the container without overlapping under free translations and rotations. Different formulations of packing soft polygons are stated and the corresponding nonlinear programming models are formulated. A solution approach is proposed based on the multistart strategy combined with a feasible starting point algorithm and a decomposition technique. Computational experiments for packing soft rectangles, triangles, pentagons, heptagons in optimized containers are provided. Directions for future research are discussed.

Keywords: Soft Polygons, Area and Convexity Conservation, Optimized Container, Packing Conditions, Quasi-phi-functions, Nonlinear Optimization.

1.2
Decoupling Geometry from Optimization: an Open-Source Collision Detection Engine for 2D irregular Cutting and Packing problems

Jeroen Gardeyn*, Greet Vanden Berghe*, Tony Wauters*
* *KU Leuven (Belgium)*

2D cutting and packing (C&P) problems involve placing a set of smaller items within the bounds of a larger container. This broad class of problems can be very challenging to solve, especially when the items and containers are irregular (non-rectangular) in shape. This difficulty has led to a highly active research domain featuring many approaches to many variants of the problem. While the objectives and particulars of these irregular C&P problems can differ, they all share the need for a specific feasibility check: determining whether or not an item can be placed at a certain position. This check is particularly complex due to the geometric irregularity of the items and containers. The general problem of collision detection also prominently arises in other fields, such as computer graphics and simulations. This seemingly simple problem is so challenging that entire books have been dedicated to this subject. For C&P problems, there is currently no sufficiently general approach to tackle this task in an easy and efficient manner. This not only heightens the barrier to entry for those who must address such problems, but also results in different researchers having to continuously reinvent the wheel whenever they are addressing new problems or developing new approaches for existing problems. This work aims to decouple geometry from optimization and develop a high-performing adaptable engine, capable of efficiently handing the geometric component of irregular C&P problems. We envisage two target audiences. First, there are those who simply want to focus on their optimization problem at hand and who would therefore greatly benefit from having an engine they can incorporate into their own methodology. Such an engine would essentially outsource the geometric challenge and enable them to focus their efforts on developing smart solution methods. The second target audience are those who, rather than solving problems themselves, might have good ideas concerning how to further improve and refine this open-source engine. The project is called jagua-rs. It is written in Rust and is publicly available at: https://github.com/JeroenGar/jagua-rs
Keywords: 2D, irregular, collision detection, open-source.

1.3
Applying Zero-Waste Design Principles: Case Studies on Pattern Manipulation Strategies for Cutting and Packing Optimisation

Nesma ElShishtawy*, Julia Bennell*, Pammi Sinha*
* *Leeds University Business School, Leeds University Business School, School of Design University of Leeds*

As the environmental cost of the fashion industry practices increases, the urgent need for a shift towards sustainable fashion practices is evident, particularly in the avenue of fabric cutting waste in garment production. This waste is exacerbated by the disconnection between design and production processes. Zero Waste Fashion Design (ZWFD) aims to address this by incorporating pattern cutting into the design stage to reduce waste, but its techniques can limit design creativity and are challenging for mass production. The fashion industry operates within a well-established structure of practices motivated by achieving the lowest cost at any price, leading to an industry that would often resist change. To overcome this issue, we propose a novel approach that infuses sustainable practices within existing industry practices, through the integration of the ZWFD principles into the existing cutting and packing optimisation processes. At its core it is an optimization algorithm inspired by the two-dimensional irregular strip packing problem, designed to iteratively adjust patterns while minimizing waste and preserving the original design's integrity. This approach was developed through extensive literature review on ZWFD, an observational study of a fashion designer crafting zero-waste trousers, and three case studies experimenting with various pattern manipulation techniques. To ensure the algorithm's suitability for practical use, we hypothesized that a bottom-left fill heuristic would offer the required computational speed and efficiency. Our tests involved six textile datasets from the ESICUP website, each modified to apply different pattern manipulation techniques, and a digitalized pattern from our observational study. The goal was to compare our algorithm's efficiency against traditional methods and evaluate its impact on the aesthetics and functionality of zero-waste designs. The findings reveal that integrating pattern manipulation techniques with the bottom-left fill heuristic not only reduces computational time but also achieves high-quality results compared to more complex algorithms like guided local search. Significantly, the algorithm developed trousers with superior lay plan efficiency, aesthetics, and functionality compared to the zero- waste design from our observational study. These results underscore the potential of our approach in blending ZWFD principles with practical, scalable fashion production techniques.
Keywords: Cutting and Packing, Sustainable Fashion, Two Dimensional Irregular Strip Packing Problems, Optimisation Models, Zero-Waste Fashion Design, Sustainable Garment Manufacturing, Algorith-

mic Design In Fashion.

1.4

Models and optimization methods for solving irregular packing and covering problems

Sergiy Yakovlev*, Oleksii Kartashov*, Dmytro Podzeha*, Iryna Yakovleva†

* *National Aerospace University "Kharkiv Aviation Institute", Department of Mathematical Modeling and Artificial Intelligence, 17 Vadima Manka st., 61070 Kharkiv, Ukraine*

† *National University of Urban Economy in Kharkiv, Department of Computer Science and Information Technology, 17 Marshala Bazhanova st., 61002, Kharkiv, Ukraine*

The paper is devoted to the study of planar irregular packing and covering problems. The shape and metric parameters (sizes) of items are assumed to be given. Items can be rotated. Three formulations of optimization problems are considered. In the first task, we pack a fixed number of items into a minimum area container of a given shape. The second task is to maximize a coverage of a bounded area when its metric parameters are fixed. The third task is to determine the full coverage of the region of maximum area of a given shape. The variables of the optimization problems are placement parameters of items, which specify their location, as well as the metric parameters of container (region). Mathematical models of these tasks as nonlinear optimization problems are proposed. We prove that packing problem can be formulated as maximum coverage problem and propose ways to formalize the basic constraints of packing problem (inclusion and non-intersection). Given the complexity of formalizing the objective function and constraints of emerging optimization problems, we recommend using computational geometry packages, in particular the Python Shapely library, to calculate them. To solve Tasks 1-3, an approach based on the combined use of local and global optimization methods is described. At the local optimization stage, a so-called elastic model is proposed, which can significantly reduce the executed time to solve tasks. Global optimization is based on metaheuristic algorithms. We provide numerous numerical examples of solving tasks and analyze the runtime.

Keywords: Packing and covering problems, geometric item, irregular shape, mathematical model, optimization.

1.5

Solving Nesting Problems with Guillotine Cuts: A Novel Branch-and-Cut Algorithm

Luiz Henrique Cherri*, Adriana Cristina Cherri†, Everton Fernandes Silva‡, José Fernando Oliveira¶

* *Newfoundland Capital Management*

† *Universidade Estadual Paulista, Av. Eng. Luiz Edmundo Carrijo Coube, 14-01, 17033-360, Bauru - SP, Brasil*

‡ *Agrisapient*

¶ *INESC TEC, Faculty of Engineering, University of Porto*

A widely studied cutting and packing problem is the two-dimensional irregular strip packing problem, aka nesting problem. This problem consists of placing a set of two-dimensional irregular polygonal pieces on a board with a fixed height and a length long enough to be considered infinite. The classical objective is to minimise the length of the board used to cut all the pieces.

The two-dimensional irregular packing problem has been tackled by both heuristic and exact methods, allowing or not the rotation of the pieces. Despite the diversity of papers on this problem, there is a lack of research on the generation of cutting patterns that satisfy the constraints of guillotine cutting for irregular items, which is fundamental in the glass cutting industry (e.g. the manufacture of conservatories).

Guillotine cut constraints are very common in two-dimensional rectangular cutting problems, but in rectangular problem the cuts are always orthogonal to one of the edges of the rectangular plate. Various exact and approximate algorithms have been published for finding two-dimensional cutting patterns that satisfy the guillotine constraint, but this is not the case for irregular packing problems, where only a couple of heuristic methods were proposed in the literature to solve two-dimensional irregular cutting and packing problems with guillotine cuts.

Due to the lack of exact approaches, this paper contributes to the literature by proposing an innovative branch-and-cut method to represent and exactly solve all variants of irregular cutting and packing problems with guillotine cuts that deal with a single board (aka as bin, plate or strip), namely the irregular strip packing problem, the irregular placement problem, the irregular knapsack problem, and the irregular identical item problem. In all cases, the pieces under consideration are irregular and convex. The convexity of the pieces is not a limiting assumption, since guillotine cuts can only be imposed in problems where the pieces are convex. There is also no loss of generality, since non-convex pieces can always be approximated by their convex hull, which is the geometric property of the pieces relevant to this problem.

The branch-and-cut method is based on the well-known Dotted-Board model, and the separation algorithm resorts to the concept of the D-function. Computational results are presented for all variants of the irregular packing problem dealing with a single board, namely the irregular strip packing problem, the irregular placement problem, the irregular knapsack problem, and the irregular identical item problem.
Keywords: two-dimensional irregular packing; branch-and-cut.

2.1
Two-Dimensional Packing for Task Scheduling in High-Performance Computing

Enrico Malaguti*, Michele Monaci*, Antonio Punzo*
* *Dipartimento di Ingegneria dell'Energia Elettrica e dell'Informazione "Guglielmo Marconi", Università di Bologna, Italy*

We consider the problem of scheduling a given set of tasks on an High-Performance Computing system according to a repetitive throughput oriented architecture. In this setting, the system is used to execute the same job mix at pre-determined times of the day, in a repetitive fashion, with only small variations on the job properties.
Each repetition of a task can be scheduled with different configurations, defined by the number of computational resources assigned to it, leading to varying computing times. The objective is to schedule all tasks in a manner that minimizes the makespan.
The problem is modeled as a variant of a two-dimensional rectangular strip packing problem. The configurations associated with each task are represented as a set of rect- angular items, where the width corresponds to the number of computational resources assigned to it, and the height reflects the required computational effort.
We discuss three Integer Linear Programming formulations for this problem. The first two formulations are based on the discretization of the strips into integer coordi- nates, which serve as the insertion points for the bottom-left corner of the items. The last formulation models solutions in which items are packed into horizontal levels, the height of each level being determined by its tallest item. This formulation does not pro- vide an optimal solution, though being much easier to solve in practice than the other two formulations. Thus, we also propose a matheuristic that combines the formulations to leverage their advantages.
The effectiveness of the proposed algorithms is assessed through comprehensive computational experiments conducted on randomly generated instances. The results demonstrate that the performances of our algorithm are better than those of the ILP formulations, providing good results within reasonable computational times.
Keywords: two-dimensional strip packing; HPC scheduling; Integer Linear Program- ming; heuristics; computational experiments.

2.2
Mathematical programming for the 2D cutting stock problem with variable sized stock applied to the honeycomb cardboard industry.

Paula Terán-Viadero*, Antonio Alonso-Ayuso†, F. Javier Martín-Campo*
* *Department of Statistics and Operations Research, Interdisciplinary Mathematics Institute (IMI), University Complutense of Madrid, Madrid, Spain.*
† *DSLAB – CETINIA, Rey Juan Carlos University, Madrid, Spain.*

This work presents a linear mixed-integer optimisation model for the two-dimensional cutting stock problem with variable-sized stock. This work is done in collaboration with a Spanish company in the honeycomb cardboard sector that serves rectangular pieces obtained from previously manufactured panels. The rectangular pieces of honeycomb cardboard are commonly used in packaging to protect the contents from being damaged. The objective of this problem is to determine both the cutting patterns, and the dimensions (width and length) of the stock to produce to be later cut in the mentioned smaller pieces. The challenge lies in the limited number of stock sizes that can be defined for each order received. The cutting patterns are defined by the stock dimensions, width and length, the items included on it and the number of rows for each item. Furthermore, the model is flexible enough to cover different types of orders including cut or precut items, as well as 1-item, n-items and 1-group cutting patterns. The model has been validated with real data with high variability on its characteristics. The results indicate that the material used can be significantly reduced compared to the company's current operation. Additionally, this model enables the company to handle larger orders as well as budget cost more effectively.
Keywords: Cutting Stock Problem, Variable-sized stock, 2-stage guillotine, mixed integer linear optimisation, honeycomb cardboard industry.

2.3
A 2D Bin Packing Problem in the Sheet Metal Industry: Models and Solution Approaches

Luigi De Giovanni*, Nicola Gastaldon†, Chiara Turbian*,†
* *Dipartimento di Matematica "Tullio Levi-Civita", Università di Padova, via Trieste 63, 35124 Padova, Italy.*
† *Salvagnini Italia, via Ingegnere Guido Salvagnini 51, 36040 Sarego, Italy.*

We consider a 2D Bin Packing Problem (2DBPP) arising in Salvagnini Italia, a multinational corporation working in the sheet metal industry. The problem asks for determining efficient cutting layouts that minimize the material waste, and such that practical constraints deriving from the cutting technology are satisfied. Among them, we mention the presence of conditional safety distances between items to preserve the quality of the products, as well as the existence of hard and soft precedence relations between groups of items, that induces a production order among the cutting layouts. The class of 2DBPP is well-known in the Operations Research literature, and due to its wide range of applications several variants of the problem have been proposed during the last decades. Nevertheless, the problem under study presents a set of practical attributes that, to the best of our knowledge, has never been considered yet. We present an exact method and a matheuristic to solve the problem, both based on solving Mixed Integer Linear Programming (MILP) models. Moreover, we present a preliminary version of an heuristic approach, based on a Beam Search algorithm. All the proposed procedures keep into account the technological constraints of the problem. Computational tests have been performed on instances of practical relevance, and computational results will be presented, with a particular focus on the comparison between the proposed methods and the current company's procedure.
Keywords: 2D-Bin Packing; Sheet Metal Industry; Mixed Integer Linear Programming; Matheuristic; Beam Search; Precedence Constraints.

2.4
A new exact, graph-based approach for the Two-Dimensional Knapsack Problem with Obstacles

Alessio La Greca*, Giovanni Righini*
* *Università di Milano "La Statale", dipartimento di Informatica*

The Two-Dimensional Knapsack Problem is a generalization of the knapsack problem. Given a large rectangle of known width and height, and a set B of smaller rectangles, called boxes, each with its own width, height and value, we are tasked to find a packing of maximum value. A packing is a subset S of B such that all the boxes in S can be placed in the container in such a way that no two boxes overlap, and no box gets outside the container. Any feasible packing pattern allow for non-guillotine cuts. Moreover, we also take into account the possible presence of rectangular obstacles. The problem is NP-hard, and many implicit enumeration techniques have been developed to confront it. We propose a Branch and Bound algorithm which stems from a new graph-based representation of feasible patterns. We show how this representation has many advantages: it allows to perform many problem reduction procedures that take into account the shape of the current partial packing, avoid some redundant patterns and generally give fine-grained control over the feasible solutions encountered. We also propose a new model for the problem, which can be relaxed to obtain different upper bounds, and procedures to compute them. Computational results show that our approach is competitive with those previously proposed in the literature.
Keywords: two-dimensional, knapsack, branch and bound, strip packing, bin packing, graph.

2.5
Beam Search to Minimise Cutting Patterns with Maximum Utilisation

Marta Cabo Nodar*, Claudia O. López Soto†
* *ITAM- México*
† *UNAM - México*

In many cutting and packing problems the sole objective is to maximise the utilisation of the cutting board, while satisfying the demand of pieces to be cut. When one focuses on optimising the use of raw material, it is very likely that for each board we will have to enter different cutting coordinates. In operations that involve a large number of pieces many boards will be required, so the cutting process can be highly affected when changing boards. When dealing with a heterogeneous mix of pieces, this problem cannot be avoided. However, when the set of pieces to be cut present large repetitions of the same pieces, it would seem reasonable to pay attention to the number of changes in the machine settings, reducing the cutting process time.

In this problem we introduce a new objective in the classic two-dimensional bin packing problem, where on top of maximising the total utilisation, we are also interested in minimising the number of different patterns needed to complete the demand. For this work, a pattern is defined as the coordinates of a set of pieces that will be cut from a bin. Minimising the number of patterns, will result in less changes on the settings of the cutting machine among bins, with a reduction on total cutting times. This variant of the problem has not been widely studied and so far we have only found a work which uses a column generation model to solve this problem.
To start tackling this problem, we expand the initial work and work with a similar setting based on the glass industry, with irregular pieces that can be freely rotated and reflected. We also start by considering the restriction of separating each piece by means of a guillotine cut, which reduces the solution space and somehow limit the placement of each piece. The initial work presents a beam search strategy where each node represents a complete bin, thus the branch with minimum depth is the one with less bins, or maximum utilisation. The same idea applies in this problem, interpreting the branch depth as the number of changes in machine settings.
We introduce some novelty approaches in terms of the sorting of pieces, considering not just the largest as the first ones to place, but also taking in consideration the number of repetitions of each piece. The fact that pieces are separated by guillotine cuts, translates into irregular shapes where to place pieces after a guillotine cut is performed, thus we also look at the similarity between the angles of the pieces and the angles of each section of the bin to decide which piece to place next. Preliminary test will be shown to demonstrate the efficiency of these new criteria for sorting pieces.
We also provide initial results that confirms that the strategy of dealing with both objectives simultaneously is more effective than using existing heuristics that are mainly design for heterogenous mix of pieces.
Keywords: Beam Search, Cutting Problems, Bi-Objective optimisation.

3.1
The optimal container selection problem for parts transportation in the automotive sector

Marta Cildoz*, Pedro M. Mateo†, Maria Teresa Alonso‡, Francisco Parreño‡, Ramon Alvarez-Valdes ¶, Fermin Mallor*
* *Public University of Navarra, Department of Statistics, Computer Science and Mathematics, Pamplona, Spain*
† *University of Zaragoza, Department of Statistical Methods, Zaragoza, Spain*
‡ *University of Castilla-La Mancha, Department of Mathematics, Albacete, Spain*
¶ *University of Valencia, Department of Statistics and Operations Research, Burjassot, Valencia, Spain*

The paper tackles the complex issue of selecting the optimal container for parts transportation within the automotive sector, focusing on a dual approach based on the mode of part placement within containers: individual placement and bulk loading. The methodology for individual placement involves a detailed geometric analysis of each part to determine the most space-efficient arrangement within a container. This includes the calculation of minimum bounding cuboids for various placement configurations such as interlocking or stacking, followed by a two-phase optimization process to select the best container arrangement. The first phase involves generating possible layer configurations within the container, while the second phase selects the optimal combination of these layers using a knapsack problem approach, ensuring that the selected arrangement does not exceed the container's volume or weight constraints.
For bulk transportation, where parts are not individually placed but rather poured into the container, a statistical learning approach is employed. This method utilizes historical data on similar parts and their packing densities within various containers to estimate the number of parts that can fit in a given container. The methodology leverages non-parametric regression techniques, where the regressor variables include the dimensions of containers and the number of similar parts previously transported in bulk. This approach accounts for the variability in packing densities that can occur with bulk loading, providing a more flexible and adaptive estimation process.
Both methodologies are integrated into a comprehensive decision support system designed to streamline the container selection process. This system takes into consideration not only the geometric fit and packing density of parts but also the associated transportation and handling costs, including the cost of returning empty containers to suppliers. By providing a holistic view of the logistics involved, the system aids in making informed decisions that optimize both space utilization and cost-efficiency in parts transportation.
This innovative approach to container selection in the automotive logistics domain exemplifies a significant advancement in addressing both economic and environmental concerns, offering potential for substantial cost savings and enhanced sustainability in supply chain management.
Keywords: Logistics, Automotive industry, Container selection, Packing, Integer optimization.

3.2

Math-heuristic Approach for Truck Packing with Delivery Deadlines: Roadef 2022 Challenge

Francisco Parreño*, María Teresa Alonso*, Ramón Álvarez-Valdés†
* *Universidad de Castilla-La Mancha*
† *Universidad de Valencia*

Efficiently packing items into trucks while adhering to delivery deadlines is critical, with far-reaching implications. In response to the Roadef 2022 challenge, we present a novel approach that combines mathematical modeling and heuristic techniques to address this complex problem. Our methodology begins by formulating the problem through integer programming, meticulously capturing its constraints and objectives. Subsequently, we introduce a heuristic algorithm designed to strategically place items, considering all pertinent factors. To tackle the challenge's unique requirements, we incorporate temporal considerations by partitioning the problem into manageable windows, facilitating more effective allocation strategies. Additionally, we decompose the global problem into connected components, capitalizing on their independent nature to enhance optimization. The decomposition into connected components enhances scalability and efficiency, enabling parallel processing of subproblems and facilitating the optimization of the overall packing solution.
We propose a heuristic algorithm based on a mixed-integer formulation for the problem. The algorithm first solves a relaxed version of the problem to identify a promising set of items to be loaded on each truck. Then, it uses a heuristic procedure to assign the items to the trucks while respecting the time windows. Computational experiments on benchmark ROADEF instances demonstrate the efficiency of the matheuristic. By striking a balance between mathematical rigor and heuristic flexibility, it offers a scalable strategy for real-world instances characterized by strict delivery deadlines. The proposed method can be extended to incorporate additional constraints and objectives arising in real logistics settings.
Keywords: Packing optimization; Heuristic algorithms; Integer programming; Time window partitioning; Matheuristic.

3.3

A load balance methodology for multi-compartment tank-truck loading problem in road fuel transportation

Ângelo Soares†, Roberto Paixão*, António G. Ramos*, Elsa Silva‡
* *INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal*
† *INESC TEC, Porto, Portugal*
‡ *ALGORITMI Research Center/LASI, University of Minho, Braga, Portugal*

This work addresses a multi-compartment tank-truck loading problem for fuel distribution. In this context, there is a set of customers (gas stations) with specific demands that must be fulfilled. To supply the gas stations, a tank truck with multiple compartments is considered, and each compartment can only carry one type of product. Therefore, it is necessary to allocate the customers' orders to different compartments. In relation to the cutting and packing problems, bins are represented by compartments with fixed dimensions, whereas items are variable and represented by fuel orders. In addition to fuel distribution, the aim is to ensure the safety of the load throughout the entire route, encompassing departure from the distribution center and each subsequent stop. To assess load safety, a Load Distribution Diagram (LDD) is employed, which is a two-dimensional graph delineating the maximum allowable load of a vehicle based on the longitudinal position of its center of gravity. The graph defines the area where the location of the load's center of gravity is permissible. For the vehicle to comply with safety standards, the center of gravity must remain within this region throughout the entire journey. It is noteworthy that this problem does not deal with routing and the route is treated as an input. To solve this problem, we developed a mixed-integer linear programming model incorporating capacity, demand, and load balancing constraints. This model is an extension of the model proposed by Silva et al. (2018). Three objective functions were considered: minimize costs by minimizing the number of compartments allocated to a gas station, maximize profits by maximizing the amount of fuel delivered, or improve safety along the entire route by minimizing the distance between the front of the tank and the load's center of gravity. The computational study demonstrated that LDD constraints are essential to ensuring load stability and safety throughout the route. Without these constraints, solutions do not comply with safety standards in 78In conclusion, this work presents several contributions to the literature. We developed a mathematical model for a new problem that simultaneously considers fuel transportation and cargo security. We have also adapted the original LDD for fuel transportation. Lastly, a new problem generator has been developed specifically for this type of problem. Reference: Silva, E., Ramos, A. G., and Oliveira, J. F. (2018). Load balance recovery for multi-drop distribution problems: A mixed integer linear programming approach. Transportation Research Part B: Methodological, 116:62–75

Keywords: Safety, Load stability, MILP, LDD, Fuel transportation.

3.4

Heuristics for industrial online three-dimensional packing problems

Sara Ali*, António Galrão Ramos†, José Fernando Oliveira*
* *INESC TEC, Faculty of Engineering, University of Porto*
† *INESC TEC, School of Engineering, Polytechnic Institute of Porto*

This study aims to develop applicable heuristics for online 3D packing problems (3D-PPs) to bridge one of the main gaps between academic research and industry practices. Online 3D-PPs arise in many industrial settings like e-commerce warehousing, where items are revealed one by one and must be packed instantly without prior information on the quantities and sizes of the next items. We focus on the classical type where rearranging packed items is not allowed, with the objective of minimizing the total number of used bins. Given the combinatorial complexity and necessity for immediate packing in online settings, heuristic methods become crucial in finding suitable solutions within a reasonable timeframe. However, the literature is quite sparse concerning appropriate heuristics for solving online 3D-PPs, and few existing ones have limited practical applicability due to the oversimplification of real-world requirements. Static stability, as an essential requirement, plays a crucial role in maintaining the position of items during packing. Its practical relevance is significant, as unstable items can cause injuries to personnel or damage to cargo. Hence, when developing heuristics for online 3D-PPs we have a specific focus on static stability strategies. To achieve practical heuristics, we outlined three key steps as follows: First, a thorough review is conducted to establish the current state of the literature on 3D-PPs by classifying major constraints and solution methods for offline and online problems based on an insightful structure. It also assists in identifying basic offline rules adaptable to online heuristics. Second, guided by insights about the adaptability of offline rules, several basic online heuristics with complementary performance on different instances are developed. To ensure comparability with existing heuristics, we incorporate the same constraints, i.e., basic geometric and blocking constraints, into our heuristics. A comparative analysis shows the superior or equivalent performance of our heuristics in terms of the number of bins used. Third, to enhance the practicality of heuristics and identify the best approach for ensuring the safety of the cargo during loading/unloading operations, four static stability constraints are embedded in online heuristics. These constraints include full-base support, partial-base support, center-of-gravity polygon support, and novel partial-base polygon support. Initially, we conduct a comprehensive analysis to evaluate the impact of constraints on the heuristics' efficiency, particularly regarding the number of used bins. The results indicate that heuristics with support polygon-based stabilities outperform others. Then, we assess the quality of these constraints in establishing stable packing layouts, using the 'static mechanical equilibrium' approach as a benchmark. The findings reveal that, within packing layouts generated under each constraint, more than 87% of items are stable. Notably, full-base and partial-base support constraints perform better than support polygon-based ones. This highlights the trade-off between efficiency (measured by the number of used bins), and effectiveness (measured by the percentage of stable items) when selecting an appropriate static stability strategy. In sum, we contribute to efficiently solving real-sized online 3D-PPs by developing practical heuristics and offering valuable insights for researchers and practitioners in this field.
Keywords: Online 3D packing problems, Packing heuristics, Static stability constraints.

4.1

The diamond cutting problem

Jonas Tollenaere*, Tony Wauters*
* *KU Leuven, Department of Computer Science, Gebroeders de Smetstraat 1, 9000, Gent, Belgium*

The diamond cutting industry is continuously faced with the challenge of extracting the maximum value from rough diamonds. In the initial phase of their processing chain, a rough diamond is digitized by scanning it to create a high-definition geometric model on which all impurities are subsequently mapped. This is the input data for a complex optimization problem that planning experts are faced with. These planners have to decide which of the traditional diamond shapes will be cut and where they are located in the material. Well known examples of these traditional shapes are the brilliant, cushion and emerald cut. The objective is to maximize the value of the extracted polished diamonds, subject to additional customer preferences. This value, or market price, is mainly driven by the 4 Cs of polished diamonds: Carat, Clarity, Color and Cut.
While the three-dimensional and irregular geometry already results in relatively challenging cutting and packing problems, the real world context of diamond cutting industry gives rise to many additional difficulties that make solving them extra complex. Examples of these difficulties are the non-linear pricing functions, parameterized

shapes and laser-sawing cutting constraints. This presentation will comprehensively introduce the diamond cutting problem, whilst paying attention to the many facets that make it an interesting challenge.
Keywords: diamond cutting, maximum volume extraction, 3D irregular cutting and packing.

4.2
3D Irregular Cutting and Packing for the Nuclear Waste from Tokamak Fusion Reactor

Yifu Wei*, Julia Bennel*l, Hamish Carr*, and Tatiana Romanova*
* *University of Leeds*

The fusion reactor is widely regarded as the ideal future source of green energy. Nevertheless, during the operation and decommissioning, the fusion reactor inevitably generates radioactive waste ranging from low-level waste (LLW) to intermediate-level waste (ILW). The waste must be stored in waste disposal facilities for a significant length of time for legal and safety reasons. Subsequently, an optimised strategy of cutting and packing is critical to reduce overall costs which means a trade-off between cutting cost (the length of cutting trajectory) and the packing cost (the number of containers utilised). My PhD research aims to tackle a 3D irregular cutting and packing problem: the primary shapes of the fusion reactor are treated independently, divided into distinct sub-problems. Each shape must be cut and subsequently packed into fixed containers. Regarding the containers, they are of a fixed, cylindrical or cubical design. The values of their cross-sectional area and height are predefined as parameters within the model. For each container, we also consider other parameters including the maximum permissible weight, maximum volume and the upper limits of radioactivity. The objective is to minimise the overall cost of cutting and packing. In terms of geometric tools, in our research, we consider (1) The raster method, which represents the shapes and packing space by discretisation; (2) The no-fit polygon, which helps determine the positional relation of two shapes; (3) The phi function technique, which provides accurate and continuous measurement for the positional relationship of two geometric objects. We also compare the tools by highlighting their advantages and disadvantages, respectively.
In terms of optimisation, the methods we considered are divided into mathe- matical programming models and heuristics/metaheuristics. Based on the char- acteristics of our problem, we aim to find the most appropriate tools which can
obtain good solutions in an acceptable time.
In the future plan, my research will follow the following steps: (1) A 2D irreg- ular bin packing problem was solved by using the phi-function technique with metaheuristics. (2) Combining cutting strategies and bin packing algorithms in the 2D scenario, and explore how cutting strategy influences the packing lay- out. (3)Integrated irregular 3D cutting and packing considering the real-world constraint regarding the context of fusion decommissioning.
Keywords: Tokamak fusion reactor, nuclear decommissioning, 3D irregular cutting and packing, Non-Fit Polygon, Phi-function, heuristics, metaheuristics.

4.3
Algorithm for On-Line Irregular 3D Packing

Pedro Rocha* , António Ramos* , Elsa Silva†
* *INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal*
† *University of Minho, Portugal*

The Irregular 3D Packing problem is still a challenging problem due to a multitude of both general, and specific characteristics, linked to the case of application. Traditional approaches are designed to deal with a set of known (Offline) rectangular boxes aiming to find their relative placement configuration inside one, or more containers. The current problem in this work is the On-Line variant, where items must be packed as soon as they arrive, with no previous information about their characteristics (shape, weight, etc) but containing irregular structures. The packing is particularly challenging due to the real-time nature of the process, where finding the adequate accommodation of the received irregular items in their order of arrival requires adequate and efficient approaches to make correct and immediate decisions. The proposed approach aims for efficient use of the container volume while addressing stability problems that arise during pallet assembly(static) and its transportation(dynamic). Static stability is tackled by evaluating the balance and weight distribution of irregular items as items are placed, carefully selecting placements to prevent collapses inside the container. The irregularity of the items increases the difficulty since their balance, weight distribution and support area relative to other items that support it must be considered. All these problems are aggravated during transportation, where vertical and horizontal accelerations lead to instabilities, collapses and potential damage if item support limits are exceeded. The placement and the

static stability are addressed using an heuristic approach assisted by a physics based simulation environment that validate the selected placement considering the items structural integrity (deformation and compressibility) and lateral acceleration limits during transportation (dynamic stability). This process is monitored in parallel using a Machine Learning algorithm that learns to identify potential placement positions that satisfy static and dynamic stability constraints, without a significant impact in computational cost (compared to the traditional approach). This work provides an approach for On-Line 3D Irregular Packing, where irregular items are tightly packed (volumetric efficiency) without previous information about their characteristics following their arrival sequence, resulting in stable configurations during assembly and transportation, that reduce collapses, deformations, and catastrophic structural failures. Acknowledgments: This work is co-financed by Component 5 - Capitalization and Business Innovation, integrated in the Resilience Dimension of the Recovery and Resilience Plan within the scope of the Recovery and Resilience Mechanism (MRR) of the European Union (EU), framed in the Next Generation EU, for the period 2021–2026, within project Produtech R3, with reference 60.
Keywords: Online Irregular Packing, Static and Dynamic Stability, Physics Based Simulation, Machine Learning

4.4

Simulation of 3D volume filling with non-spherical and sperical titanium alloy powder particles for additive manufacturing

Alexander Pankratov*, Yuri Stoyan†, Tetyana Romanova*,†, Igor Lemishk‡, Zoia Duriagina‡
* *Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, Pozharskogo St., 2/10, Kharkiv, 61046, Ukraine*
† *University of Leeds, Maurice Keyworth Building, University of Leeds, Leeds, LS2 9JT, UK*
‡ *Lviv Polytechnic National University, 12 Bandera St., Lviv, 79013, Ukraine*

This study is aimed to develop an approach to modeling the layer-by-layer filling of a certain 3D volume with a combination of non-spherical and spherical powder particles of different fractional composition. A mathematical model of the problem of packing regular and irregular freely moving objects is provided using the phi-function technique. A heuristic algorithm that uses nonlin-ear optimization is proposed for calculating packing density factor/porosity. The results of numerical modeling are compared with experimental data obtained for a mixture of spherical and polyhedral powders of titanium alloys. It is established that the relative frequencies obtained by the developed algorithm correspond to the experimental results with high accuracy. This indicates the possibility of using the results of numerical modeling instead of costly experimental studies. The use of mathe-matical modeling and optimization techniques in additive manufacturing makes it possible to im-prove the efficiency of each stage of the technological process, reduce the number of defective products, and rationally plan the consumption of energy and material resources.
Keywords: packing, spherical and non-spherical particles, 3D volume, mathematical modeling, nonlinear optimization, additive manufacturing.

5.1

Robust Bin Packing Problem with Fragility Constraints

Heloisa Vasques da Silva*, Alberto Locatelli†, Silvio Alexandre de Araujo‡, Manuel Iori†
* *São Paulo State University (UNESP), Avenida Eng. Luís Edmundo Carrijo Coube, 14-01, Vargem Limpa, Bauru-SP, Brasil*
† *DISMI, University of Modena and Reggio Emilia, via Amendola 2, 42122 Reggio Emilia, Italy*
‡ *São Paulo State University (UNESP), Rua Cristóvão Colombo, 2265, Jardim Nazareth, São José do Rio Preto-SP, Brasil.*

In the Bin Packing Problem with Fragility Constraints (BPPFC), we are given n items of weight w_j and fragility f_j $(j = 1, \dots, n)$ and a large number of uncapacitated bins. The problem consists in packing all items into the minimum number of bins, ensuring that the total weight packed in any bin does not exceed the smallest fragility among the set of items assigned to the bin. This problem appears in the telecommunication field, where each call is characterized by a noise and a noise tolerance. Therefore, the assignment of calls to available channels cannot exceed the noise acceptance limit of the fragilest call in the channel. Considering the fact that the noise of the calls is not exactly known in advance, but typically belongs to a given interval, in this work we address a variant of the BPPFC designed to represent data uncertainties affecting the weights. The resulting Robust Bin Packing Problem with Fragility Constraints (RBPPFC) uses a budgeted uncertainty set, where in each bin at most Γ items in the solution can change from their nominal weight. A feasible solution must obey the fragility

constraint no matter what the actual weight of each item turns out to be. Starting from the Dynamic Programming (DP) algorithm for the 0-1 Knapsack Problem, we introduce two models to solve the R-BPPFC: a compact mixed-integer linear programming model, and an arc flow formulation based on the DP algorithm. To assess the efficiency of the models and compare them with each other, we have tested them on a set of adapted instances from the literature, identifying the methods that yield the best results.
Keywords: Bin Packing Problem. Robust Optimization. Dynamic Programming. Arc Flow formulation.

5.2
Column generation for cutting stock problem with usable leftovers in industrial joinery

Victor SENERGUES*,†, Nadjib BRAHIMI†,‡, Olivier PETON*,†
* *IMT atlantique, Nantes, France* † *Laboratoire des sciences et du numérique de Nantes LS2N, Nantes, France* ‡ *Rennes School of Business, Rennes, France*

The presentation will explore a one-dimensional cutting stock problem with usable leftovers specific to industrial joinery. This industry is characterized by the length of the items which are generally large in relation to the material from which they are cut. On average, an item represents 20% of an object, and with a considerable portion of items having unitary or double demand. Consequently, production plans often yield significant leftovers. Depending on the joinery type, these leftovers can be used to meet future demands. Bay window frames tend to generate long leftover that can be used for smaller window frames. In this context, we propose a study of a Cutting Stock Problem with Usable Leftovers (CSPUL), tailored to our industrial context. In scenarios where manufacturers operate multiple production sites, sharing raw materials, efficient transportation, and storage of usable leftovers (also called retails in the literature) between sites become paramount. To address this, we categorize leftovers into two types: standard retails with predefined lengths, low stocking costs, low cost of usage (compared to a raw supply) and high stocking capacity suitable for exchange between sites, and non-standard retails lacking predefined lengths, having higher stocking costs but significantly lower cost of usage, really low stocking capacity and being non-transportable. Cutting stock problems with leftovers have received a lot of interest in the last two decades both for the one-dimensional and two-dimensional models. The proposed models mostly attempt to minimize the total cost of used material while generating leftovers that can be used in future periods. Our model aims to devise a production plan that minimizes both waste and associated costs while factoring in object prices, stocking expenses, and waste-related costs. The proposed approach minimizes production costs while effectively managing the generation and utilization of distinct types of retails, facilitating seamless integration of selling or internally using leftovers. The model offers high adaptability, accommodating scenarios with standard retails, non-standard retails, or both, as per the industrial context, with a focus on delivering fast, high-quality solutions. To achieve this, we employ column generation to solve the relaxed problem and use rounding heuristics from existing literature to obtain optimal solutions efficiently. The presentation will showcase promising outcomes derived from real-world datasets, underscoring the significant benefits of exploiting production leftovers in optimizing industrial processes.
Keywords: Cutting Problem, Reusable Leftovers, Column Generation, Heuristics.

5.3
Mathematical formulations for wood recycling optimization

Bessemans Pauline*, Paquay Célia*
* *HEC – Liège, Management School of the University of Liège, Belgium*

The increasing demand for materials such as wood undeniably contributes to the depletion of natural resources and global warming. In order to stop this phenomenon, a more sustainable and circular management of wood could be developed by intelligently recycling our wood waste. This recycling has a lot of ecological potential. A part of the wood waste is in the form of beams or pallets and could be recycled by being considered as wood slats. These wood strips could then be combined, assembled, and glued to create Cross-Laminated Timber (CLT) panels for use in the construction industry. We aim to develop optimization techniques to revalue raw wood waste by providing the layout schemes to build CLT panels. The objective can be to produce as many CLT panels as possible or to minimize the wood surplus when a given set of panels should be produced. A literature review has been performed to identify the relatively similar problems that have been modeled and analyzed by experts in operations management and mathematical optimization. The two closest problems to ours are the skiving stock problem and the dual bin packing problem. The latter is quite misleading since our problem is technically not a

dual version of the cutting stock/bin packing problem, but a problem on its own as shown in the literature. In this work, we propose a clear description of our problem and different mathematical formulations for the different variants. We also add several cuts to improve the formulations. They are then tested with various numerical experiments based on field data from the wood industry. As it is an NP-hard problem since it is a special case of 3-partition, we identify the limit size of the instances for which the problem can still be solved in a reasonable amount of time.

Keywords: dual bin packing problem, skiving stock problem, integer linear programming wood recycling.

5.4

Bounding Procedures and Exact Arcflow Formulations for the Bin Packing Problem with Minimum Color Fragmentation

Mathijs Barkel*, Maxence Delorme*, Enrico Malaguti†, Michele Monaci†

* *Tilburg University, Department of Econometrics and Operations Research, 5037 AB Tilburg, The Netherlands,*
† *Università di Bologna, Dipartimento di Ingegneria dell'Energia Elettrica e dell'Informazione "Guglielmo Marconi", Viale del Risorgimento, 2, 40136, Bologna, Italy*

The Bin Packing Problem with Minimum Color Fragmentation (BPPMCF) is a recently introduced extension of the well-known Bin Packing Problem (BPP). Given a set of weighted, colored items and a limited number of bins with identical capacity, the objective is to avoid color fragmentation by packing items of the same color as much as possible in the same bins. This problem has applications in several real-life problems in fields such as production planning, logistics, surgical scheduling and group event seating. To solve the BPPMCF, we introduce several BPP-based bounding procedures, one of which can solve all existing benchmark instances to optimality within a few seconds. Moreover, we introduce three exact methods based on the well-known arcflow formulation for the BPP, which we show to be effective, even on a new relevant benchmark of harder instances.

Keywords: packing, bounds, integer programming, arcflow formulations, computational experiments

6.1

A Deep Reinforcement Learning Approach for the 3D multiple bin packing problem

Evers Justine* and Schyns Michaël*

* *HEC Liège - Management School of the University of Liège, Belgium*

This study investigates a variant of the 3D Bin Packing Problem (3DBPP), a computationally challenging NP-hard task involving the optimal packing of cuboid boxes into containers with limited capacity while satisfying non-overlapping constraints between the different objects. 3DBPP is a major problem faced by many companies and is much more difficult to solve than the 2D version. First due to the combinatorial nature of the problem induced by a third dimension, but also since additional constraints must be taken into account to handle real-life problems; e.g. multiple bins context, vertical stability, horizontal stability, fragility, weight distribution... Our work investigates the case of the 3D Multiple-Bin Packing Problem (3D-MBPP), taking into account the stability. Obtaining good feasible solutions for such complex problems remains a challenge for traditional Operations Research methods. Some authors therefore started to consider alternative approaches from other research streams, namely Artificial Intelligence (AI) and Machine Learning (ML). In particular, Reinforcement Learning (RL) has been adapted and tested in the literature in order to accommodate combinatorial problems. In RL, an "agent" interacts with an "environment" by performing actions and receiving feedback in the form of "rewards," iteratively learning optimal action sequences. Deep Reinforcement Learning (DRL) further enhances this approach by incorporating ML into the process, essentially to deal with the huge size of the solution space.

While this DRL approach represents a significant step forward, our literature review reveals limitations in previous studies. Existing works often address a too-restricted set of constraints, or neglect crucial aspects like stability and orientation constraints. Additionally, the focus heavily leans towards single-bin scenarios, overlooking the more realistic multiple-bin setting.

Therefore, this research addresses these three main challenges outlined hereabove: (1) the inherent complexity of 3DBPP rendering classical methods inefficient, (2) the limited constraint consideration in prior DRL applications, and (3) the lack of attention to multiple-bin scenarios.

We build upon an existing DRL model for 3DBPP only, which considered one infinite-height bin and did not take the stability of the packing into account. We developed a Python-based implementation to test our DRL approach on several artificial instances of different sizes with identical bins (Single Bin Size Bin Packing Problem). After an initial training of several hours, our system is able to provide, in a few seconds, highly packed solutions for realistic large-scale instances (100 heterogeneous parcels loaded in identical 120 x 120 x 100 bins with a 1cm

precision).
Keywords: Combinatorial Optimization, Bin Packing Problem, Container Loading Problem, Logistics, Artificial Intelligence, Machine Learning, Reinforcement Learning.

6.2
Solving the two dimensional strip packing problem using reinforcement learning framework

Fatih Burak Akçay*, Maxence Delorme*
* *Econometrics and Operations Research department, Tilburg University*

In the two-dimensional strip packing problem (SPP), the goal is to pack items into a strip of fixed width, minimizing the height of the packing. One of the most efficient ways to solve the SPP is using a decomposition algorithm, where the problem is split into two subproblems: primary and secondary problem. In the primary problem, a relaxation of the SPP is solved, such as one-dimensional contiguous bin packing problem (1CBP) or parallel processor scheduling problem (P|cont|Cmax). From a feasible solution in the primary problem, the secondary problem constructs a feasible SPP solution. If no such solution is found, techniques like adding a cut or banning the current solution from the solver are employed. Various formulations exist for the primary problem, including different integer linear programming models (such as flow-based or discrete time scheduling-based formulations) or constraint programming models. Empirical results show that different solution approaches perform best for different instances, indicating no single dominating formulation. Our work focuses on developing automated hyper-algorithms capable of selecting the most suitable method or sequence of methods to solve a given instance, aligning with the trend of integrating machine learning techniques into optimization algorithms. We use reinforcement learning to decide on which mathematical model should be used in the primary problem along with the other features that can be incorporated in the decomposition scheme. The performance of the suggested framework is evaluated over the benchmark datasets.
Keywords: reinforcement learning, strip packing problem, decomposition.

6.3
Enhancing Last-Mile Delivery Efficiency through Geospatial Clustering and District Optimization

Farzam Salimi*, António Galrão Ramos†
* *INESC TEC, Porto, Portugal farzam.salimi@inesctec.pt*
† *INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal, agr@isep.ipp.pt*

One of the most important aspects of any last mile delivery system is efficiency which has a direct impact on reducing operational costs and improving customer satisfaction in the logistics sector. This study introduces a novel approach to optimizing delivery routes and districting using geospatial clustering. This approach focused on balancing the workload and minimizing travel time. By applying K-mean clustering to geographical data and delivery features such as weight and number of delivered packages, this research aimed to develop an optimized districting plan for last mile delivery. The objective was to identify optimally sized and geographically compact districts. The dataset belongs to a Portuguese delivery company in northern Portugal, and it comprises delivery stop coordinates', package weights, delivery times, number of packages per stop, and other delivery route information. K-mean clustering based on geographical coordinates, weights, and the number of packages was applied to this data to group delivery stops into distinct districts considering both spatial proximity and workload balance. The elbow method was applied to find the optimal number of clusters, and all the features were standardized to help the convergence speed and equal importance. We presents the comparison between the K-mean clustering method based on the weights and number of packages with the hierarchical clustering method. After careful analysis of K-mean districts with macro districts by hierarchical method, there are few differences observed regarding two specific zones, which in K-mean they clustered as one zone. K-mean method in terms of scalability, speed, flexibility, handling of outliers, and ease of interpretation is a superior technique to hierarchical clustering. The hierarchical method divided the zones into 5 macro districts based on parameters like quantity, service time, coordinates, dimension of service region, and depot location, while the k-mean method was able to produce similar results with fewer parameters. In conclusion, the k-mean clustering algorithm successfully partitioned the delivery area into 4 meaningful districts and it identified similar patterns as the hierarchical clustering methodology with 5 zones, but with considerably fewer complexities and features. This unsupervised method is characterized by geographical cohesiveness and a balanced number of deliveries, and the runtime was almost instant. In addition,

k-mean clustering based on the time of deliveries showed similar results with minor differences, and considering more features can help to understand the dynamic of districting and the features involved. We have divided these macro districts by the hierarchical methods into 49 micro districts and 257 nano districts, and for future works, the application of K-means method for dividing into micro and nano districts should be explored.

Keywords: Last-mile delivery, Machine learning, District optimization, Geospatial clustering, Logistics efficiency.

6.4

A multi-start metaheuristic for solving the problem of slitting steel plate coils

Óscar Soto-Sánchez*, María Sierra-Paradinas*, Micael Gallego* and Antonio Alonso-Ayuso*
* *Universidad Rey Juan Carlos, Madrid, Spain*

This work was developed in the context of a Spanish company in the metal industry. The slitting problem arises when large metal coils need to be cut into smaller coils to meet customer demand. The company's stock is very heterogeneous, consisting of large coils and process coils from previous slitting processes of very different sizes. The allocation of orders to coils to generate cutting patterns is a very complex process due to the heterogeneity of the stock and the restrictions imposed by the customers. The company's objective is to reduce the leftovers generated (both reusable and non-reusable) and to increase the order accuracy (the difference between the weight requested by the customer and the weight delivered). We present a heuristic algorithm capable of solving the cutting problem, which has been validated with real data and is currently in production. The results obtained improve the company's operations by reducing the leftovers generated by about 50%, while only taking a few minutes to find the solutions.

Keywords: Cutting; Steel industry; Reusable leftovers; Metaheuristics; Multi-start methods.

6.5

Sustainability of cutting and packing problems: beyond waste minimization

Matheus Campinho*, Elsa Silva†, José Fernando Oliveira‡, Maria Antónia Carravilla‡
* *INESC TEC, Federal University of Rio de Janeiro, Brazil*
† *Department of Production and Systems, ALGORITMI Research Centre/ LASI, University of Minho, Portugal*
‡ *INESC TEC, Faculty of Engineering, University of Porto, Portugal*

The complexity of cutting patterns in Cutting and Packing (C&P) problems is often underestimated. This leads to simplistic cutting approaches in many industries. In this talk, we will address the complexity of cutting patterns beyond the "usual" goal of waste reduction. We will focus on Two-Dimensional Single Large Object Placement Problems (2DSLOPP), which involve maximizing output value by packing small items into a large object, while considering quantity requirements and associated values. Despite the importance of reducing waste, our goal is to improve the understanding of the problem by integrating waste minimization and pattern complexity minimization in a multi-objective framework. While waste reduction is critical, the complexity of the resulting cutting patterns is often overlooked. There is a prevailing tendency towards simplistic cutting approaches in various industries. Therefore, this research aims to deepen the understanding of the impact of geometric complexity of cutting patterns on raw material consumption. The challenge was to build on the Floating-Cuts model, a mixed-integer linear programming (MILP) model for two-dimensional (2D) rectangular C&P problems. We assess complexity by modifying the objective function and adding specific constraints to the general model, and then examine the final cutting patterns. The model incorporates complexity control by penalizing the "number of different item types in a pattern". This penalty is balanced with maximizing the total value of packed items within the large object. The model is implemented using Python and the GUROBI solver. By developing different instances, we performed several computational experiments to evaluate the performance of the model. The main finding is that the complexity control effectively reduces the number of different object types in the cutting patterns as its weight in the objective function increases. However, this reduction comes at a trade-off with the total number of item types placed in the pattern and the value of the packing density. In conclusion, this work highlights the importance of moving beyond a sole focus on waste minimization in C&P problems. By optimizing for both waste and complexity, we achieve balanced solutions that maximize output value while controlling geometric complexity. The results suggest promising economic and environmental benefits for industries to achieve more sustainable and efficient operations.

Keywords: cutting and packing problems; Floating-Cuts model; complexity of the cutting patterns.

7.1
A new construction heuristic for an online three-dimensional packing problem: a case study

Burcu Özbel *, António G. Ramos†, Pedro Rocha†
* *INESC TEC, Porto, Portugal*
† *INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal*

This work addresses a real-world problem faced by a Portuguese company, which involves daily packing of boxes (cork boards) onto a pallet using a robotic system. The development of software to implement load plans executed by a robot introduces a complexity constraint in our case. This complexity arises from the need for "robot-packable patterns", which involve cork boards being packed by a robot. Such software requires algorithms that can devise efficient and feasible packing patterns, considering the physical limitations and operational capabilities of the robot. Unlike the offline problem where the decision to pack is made knowing all the boxes and considering that they are all available for packing, in the addressed online problem the robot can only pack one box at a time without knowing the subsequent ones. No further adjustments, such as unloading or readjusting, are allowed. The robot must make an immediate decision that places the incoming box while optimizing the overall compactness of the layout within the pallet. As this is a real-world application, practical constraints, such as static stability and box orientation, must be ensured. Experiments are conducted with the data generated based on the company's operations, and the quality of the solutions is evaluated. The findings highlight the potential of our heuristic to significantly improve operational efficiency in packing.
Keywords: Online packing, Static stability, Maximal-spaces.

7.2
A column-generation matheuristic approach for optimizing a 3-stage Packing Problem

Khadija Hadj Salem*, Benoit Lardeux*, Xavier Schepler †
* *L@bISEN, Usine du Futur, ISEN Yncréa Ouest, 33 Quater Avenue du Champ de Manœuvres, 44470, Carquefou, France.*
† *Data Intelligence, Generix Group, 8 Rue Simone IFF, 75012, Paris, France.*

Dealing with pallet loading problems is a challenging and rich research area in the Cutting and Packing (C&P) literature. Different variants have been addressed in the literature such as the two-stage packing problem (Moura and Bortfeldt, 2016), and the multi-container pallet loading problem (Alonso et al, 2019 & 2020), among others. In this study, we tackle the three-stage packing problem (3-stage PP), a new C&P problem variant, that occurs in warehouse logistics. According to the typology of Wascher, 2007, the 3-stage PP combines two well-known NP-hard problems: the Bin-Packing Problem and the Pallet Loading Problem. This problem consists of minimizing the total renting truck cost to deliver clients' orders. Four decision levels are necessary to define a loading plan. The ordered boxes must be packed onto homogeneous pallets (one box type packing into full layers) or heterogeneous pallets (structured in chimney walls). The resulting pallets are then stacked while respecting the boxes's fragility. Each palette stack is dedicated to one client and must be loaded into a truck, chosen from a selection with varying loading capacities and rental costs. Loading a truck must also respect stability constraints to prevent excessive yaw. We propose a column generation approach where columns are pallet stacks. We also propose a line generation, based on an allocation problem and a fragility satisfaction check model. Computational experiments through randomly generated instances are reported to assess the effectiveness of our methods and compare them with each other.
Keywords: 3D packing, pallet building, truck loading, MILP, column generation.

7.3
Optimizing Manufacturer's Pallet Loading: Balancing Stability and Efficiency

Joao Araujo*, Antonio G. Ramos†, Elsa Silva‡
* *INESC TEC and School of Engineering, University of Porto, Porto, Portugal*
† *INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal*
‡ *ALGORITMI Research Center/LASI, University of Minho, Braga, Portugal*

Most approaches developed to solve the Manufacturer's Pallet Loading Problems focus only on maximizing the number of loaded items. However, other aspects are essential, such as the stability of the cargo. If the cargo

configuration is unstable, the items will collapse, destroying the palletization and possibly damaging items. The main goal of this work is to generate loading patterns that maximize the number of items loaded while ensuring their stability during assembly and transportation. A two-stage algorithm consisting of Mixed-Integer Linear Programming (MILP) and heuristics is proposed. The algorithm uses the 2D enclosure of the pallet and the dimensions of the items, using the MILP model to generate loading patterns. Twelve distinct variants of the MILP were created, with different combinations of five possible objective functions. While the primary objective remains constant, prioritizing the maximization of loaded items, a set of secondary objective functions introduced in a lexicographic sequence is incorporated. These secondary functions offer diverse perspectives, aiming to optimize the compactness of box arrangements along various orientations or strike a balance between vertical and horizontal box dispositions. Consequently, they yield distinct loading patterns, enriching the algorithm's versatility and adaptability to various cargo configurations. The algorithm also includes eight post-optimization heuristics that may be used to adapt the loading patterns to the real-world requirements of the users, resulting in up to of 96 possible patterns. Furthermore, the algorithm includes the possibility of generating patterns with overhanging items, which might allow one or more additional items to be packed. The algorithm also calculates stability metrics for each pattern to help the end user select the most adequate pattern. The algorithm was tested using 1917 real instances, validating its ability to generate diverse pat- terns with differing degrees of stability. Demonstrating proficiency, it consistently produced loading patterns characterized by high occupancy rates and stability. This proficiency has significant potential to reduce pallet demand, consequently reducing the number of vehicles on the road, and minimizing fuel consumption. Moreover, these optimized patterns mitigate road accidents by improving stability and promoting safer transportation practices. Initially, the MILP models were solved using the CPLEX solver, yielding optimal solutions within acceptable computational times. A second set of experiments was conducted to explore the possibility of transitioning towards open-source alternatives, such as COIN-OR and HIGHS. This phase involved a comprehensive study using the 1917 instances previously mentioned to compare the performance of the three solvers. Preliminary findings suggest that all three solvers exhibit similar effectiveness, yet only HIGHS demonstrates efficiency on par with CPLEX, indicating its potential as a viable open-source alternative.

Keywords: Pallet Loading Problem, Mixed-Integer Linear Programming, Heuristics, Stability, Open-source solvers.

7.4
Matheuristic approaches to binding the routing and cargo load balance problems

Elsa Silva*, António G. Ramos†, Ana Moura‡

* *ALGORITMI Research Center/LASI, University of Minho, Braga, Portugal*

† *INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal*

‡ *GOVCOOP and University of Aveiro, Aveiro, Portugal*

This work addresses a significant logistic challenge known as the capacitated vehicle routing problem with time window and the two-dimensional vehicle loading problem with cargo load balance constraints (2D-CVRBP). In the 2D-CVRBP, the objective is to efficiently distribute goods to various clients using identical vehicles to strict weight distribution regulations mandated by technical requirements and by regulatory authorities. Until now, axle weight distribution in determining the load plan for freight transport units has been overlooked in the vehicle routing process. Compliance with these axle weight constraints has become paramount for road freight transport companies, since noncompliance with the axle weight distribution legislation translates into heavy fines. However, the implementation of novel regulatory and technical requirements for the distribution of vehicle axle weights, in road freight transport, introduces a new set of constraints on vehicle routing. Having this in mind, this work aims to provide a tool capable of generating cargo loading plans and routing sequences for a palletised cargo distribution problem. The solution to the problem consists of a set of routes, each accompanied by a cargo loading plan. This loading plan specifies the placement locations of all client pallets visited along each route, while considering hard and soft constraints. Two integrative solution approaches are proposed, one giving greater importance to the routing and the other prioritising the loading. Both solution approaches are based on the integration of three mixed integer linear programming (MILP) models related to the (i) routing problem, the (ii) 2D loading problem with load balance and weight constraints, and the (iii) 2D loading problem with load balance, weight limit, LIFO strategy and pallet grouping constraints. Those models were combined with one algorithm and some heuristic procedures, resulting in two approaches. Since this problem has new characteristics relative to other published works, the proposed heuristics were applied to a test set obtained by adapting instances from the literature and using an instances generator. Extensive computational experiments were performed, and the computational results show the effectiveness of the proposed approaches. Acknowledgements: This work is financed by National

Funds through the Portuguese funding agency, FCT (Fundação para a Ciência e a Tecnologia, I.P.), within the project CIBELE, with reference 2022.02767.PTDC (https://doi.org/10.54499/ 2022.02767.PTDC) and within the project TacitRouting reference 2022.08808.PTDC. This work is co-financed by Component 5 – Capitalization and Business Innovation, integrated in the Resilience Dimension of the Recovery and Resilience Plan within the scope of the Recovery and Resilience Mechanism (MRR) of the European Union (EU), framed in the Next Generation EU, for the period 2021–2026, within project ProdutechR3, with reference 60.
Keywords: Load balance, Vehicle routing problem, Mixed integer linear programming, Matheuristic.

7.5
The Pallet Loading Problem on a Robotic Loader System

Davide Croci*, Ola Jabali*, Federico Malucelli*, Joe Naoum-Sawaya†
* *Politecnico di Milano, Milan, Italy*
† *Ivey Business School, University of Western Ontario, London, Canada*

We introduce the Distributor's Pallet Loading Problem on a Robotic Loader System (DPLP-RLS), in which a set of boxes is packed in a minimal number of pallets by a robot. We model the DPLP-RLS as a variant of the three-dimensional bin packing problem which includes static stability and load-bearing constraints, as well as the computation of a feasible sequence of operations for a robot to place boxes one at a time on each pallet. Finding a feasible sequence of operations involves ordering the placement of boxes and choosing a specific movement path for each box, ensuring the robot's movements avoid any collision with previously positioned boxes.
We propose a constraint programming (CP) model and a heuristic algorithm for the subproblem of finding a feasible sequence of robot operations to load a set of boxes whose placement is fixed. Both the CP model and the heuristic exploit a tailored multigraph which defines the precedence relationships between boxes to be loaded. We then solve the complete DPLP-RLS by embedding the proposed procedures in a state-of-the-art beam search algorithm for the DPLP. We evaluate our solution on adapted DPLP instances from the literature, as well as on a series of large instances obtained from our industrial partner. Experimental results reveal the ability of our approach to find high-quality solutions for industry-size instances in short computational times.
Keywords: 3d bin packing, pallet loading, beam search, robotic loader system, constraint programming.

List of Participants

Alessio La Greca,
Università degli studi di Milano
alessio.lagreca@studenti.unimi.it

Alexander Pankratov ,
Institute for Mechanical Engineering Problems of the National Academy of Sciences of Ukraine, Pozharskogo St., 2/10, Kharkiv, 61046, Ukraine
pankratov2001@yahoo.com

Ana Moura,
GOVCOPP - University of Aveiro
ana.moura@ua.pt

Ângelo Soares,
INESCTEC
angelo.v.soares@inesctec.pt

António Galrão Ramos,
INESC TEC and School of Engineering, Polytechnic of Porto, Porto, Portugal
agr@isep.ipp.pt

Antonio Punzo,
Alma Mater Studiorum - Università di Bologna
antonio.punzo5@unibo.it

BESSEMANS Pauline,
HEC-Management School of the University of Liège
Pauline.Bessemans@uliege.be

Burcu Kubur Özbel,
INESCTEC
kubur.burcu@gmail.com

Chiara Turbian,
Università di Padova, Salvagnini Italia
chiara.turbian@phd.unipd.it

Davide Croci,
Politecnico di Milano
davide.croci@polimi.it

Elsa Silva,
Department of Production and Systems, University of Minho
elsa@dps.uminho.pt

EVERS Justine,
HEC-Management School of the University of Liège
jevers@uliege.be

F. Javier Martin-Campo,
Complutense University of Madrid
javier.martin.campo@mat.ucm.es

Fatih Burak Akçay,
Tilburg University
F.B.Akcay@tilburguniversity.edu

Francisco Parreño,
University of Castilla-La Mancha
Francisco.Parreno@uclm.es

Gastaldon Nicola,
Salvagnini Italia S.p.A.
nicola.gastaldon@salvagninigroup.com

Heloisa Vasques da Silva,
Universidade Estadual Paulista
heloisa.vasques@unesp.br

Jeroen Gardeyn,
KU Leuven
jeroen.gardeyn@kuleuven.be

João Araújo,
INESCTEC
joao.araujo@inesctec.pt

Jonas Tollenaere,
CODeS, NUMA, Dept. of Computer Science, KU Leuven
jonas.tollenaere@kuleuven.be

José Fernando Oliveira,
INESC TEC, University of Porto, Faculty of Engineering
jfo@fe.up.pt

Juan J. Lastra-Díaz,
Lectra Advanced Research department
j.lastra@lectra.com

Julia Bennell,
University of Leeds
J.Bennell@leeds.ac.uk

Khadija Alice HADJ SALEM,
L@bISEN, ISEN Nantes
khadija.hadj-salem@isen-ouest.yncrea.fr

LELOUP Emeline,
HEC-Management School of the University of Liège
emeline.leloup@uliege.be

Léo Gilbert,
IMT Atlantique Nantes
leo.gilbert31@gmail.com

Maria Antónia Carravilla,
INESC TEC, University of Porto, Faculty of Engineering
mac@fe.up.pt

MARÍA TERESA ALONSO,
UNIVERSIDAD DE CASTILLA-LA MANCHA
MariaTeresa.Alonso@uclm.es

Marta Cabo,
ITAM - Mexico
marta.cabo@itam.mx

Matheus Campinho,
INESC TEC, University of Porto, Faculty of Engineering
matheus.f.campinho@inesctec.pt

Mathijs Barkel,
Department of Econometrics and Operations Research, Tilburg University, The Netherlands
M.J.Barkel@tilburguniversity.edu>

Maxence Delorme,
Tilburg University
M.Delorme@tilburguniversity.edu

Nesma ElShishtawy,
Leeds University Business School and the School of Design
bn17nre@leeds.ac.uk

Óscar Soto Sánchez,
Universidad Rey Juan Carlos
oscar.soto@urjc.es

PAQUAY Célia,
HEC-Management School of the University of Liège
cpaquay@uliege.be

Paula Terán Viadero,
Complutense University of Madrid
pauteran@ucm.es

Pedro Rocha,
INESCTEC
pedro.f.rocha@inesctec.pt

PIRONET Thierry,
HEC-Management School of the University of Liège
thierry.pironet@uliege.be

RAMON ALVAREZ-VALDES,
University of Valencia
ramon.alvarez@uv.es

Rosephine Georgina Rakotonirainy,
University of Cape Town
georgina@aims.ac.za

Sara Ali,
INESC TEC, Faculty of Engineering, University of Porto
sara.ali@inesctec.pt

SCHYNS Michaël,
HEC-Management School of the University of Liège
M.Schyns@uliege.be

SENERGUES Victor,
IMT Atlantique, LS2N
victor.senergues@reeverse-systems.com

Tetyana Romanova,
University of Leeds
T.Romanova@leeds.ac.uk

Tony Wauters,
KU Leuven
tony.wauters@kuleuven.be

Valério de Carvalho,
Department of Production and Systems, University of Minho
vc@dps.uminho.pt

Yifu Wei,
University of Leeds
pmywe@leeds.ac.uk

Campus de Gualtar
4710-057 Braga – P

Universidade do Minho
Unidade de Serviços dos Sistemas de Informação e Comunicações

Connection to wireless network for events

Configuration Guide

Table of Contents

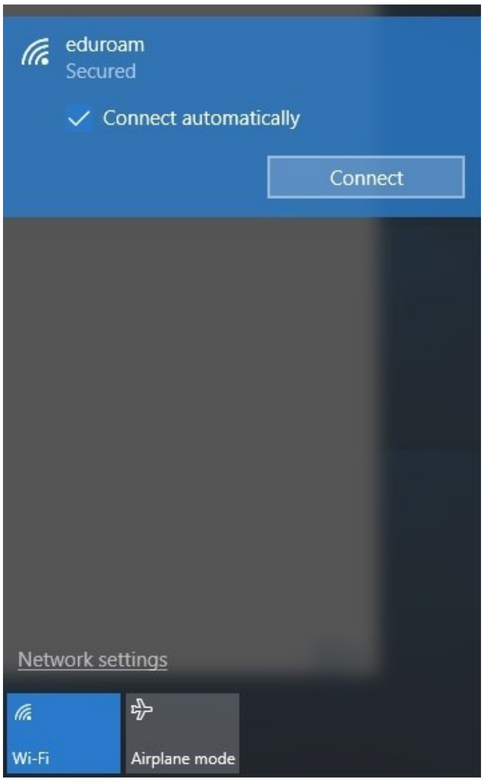
1. Windows 10

To have wireless connectivity to the Internet you must follow the following steps:

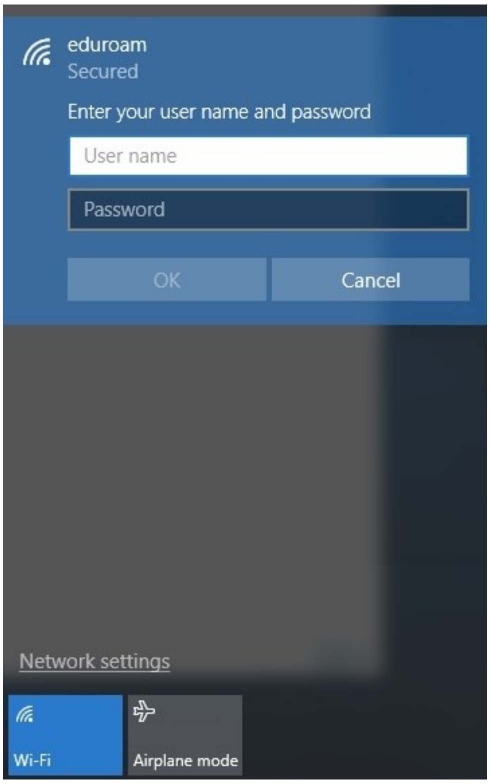
1. Using the left mouse button click on the icon .

2. From the list of available networks, click **eduroam**.

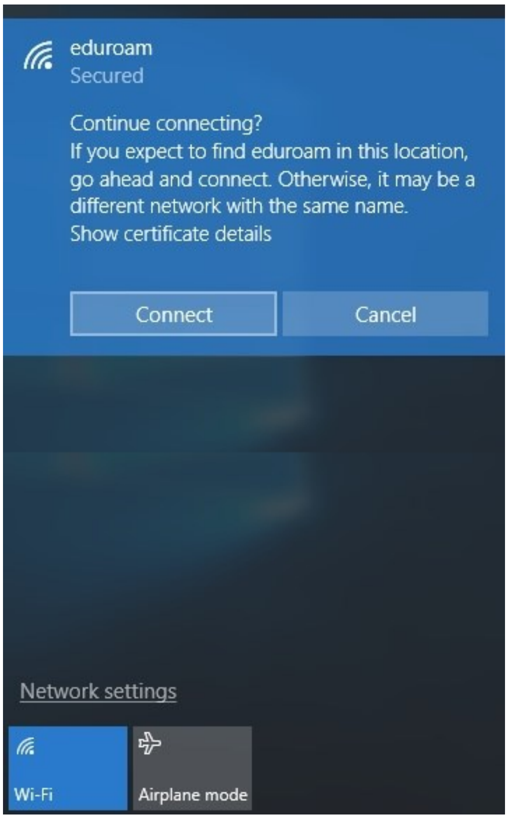
3. Click on ‘**Connect**’.



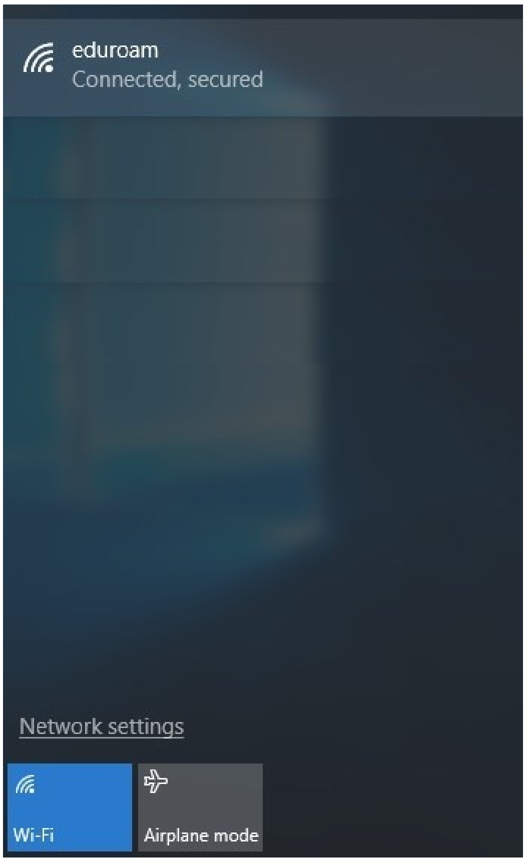
4. Insert your credentials: **username** and **password.** Click OK.



5. If the following window appears click on '**Connect**' (left option).



6. If everything is ok, the wireless network connection will be successful.



2. Windows 8

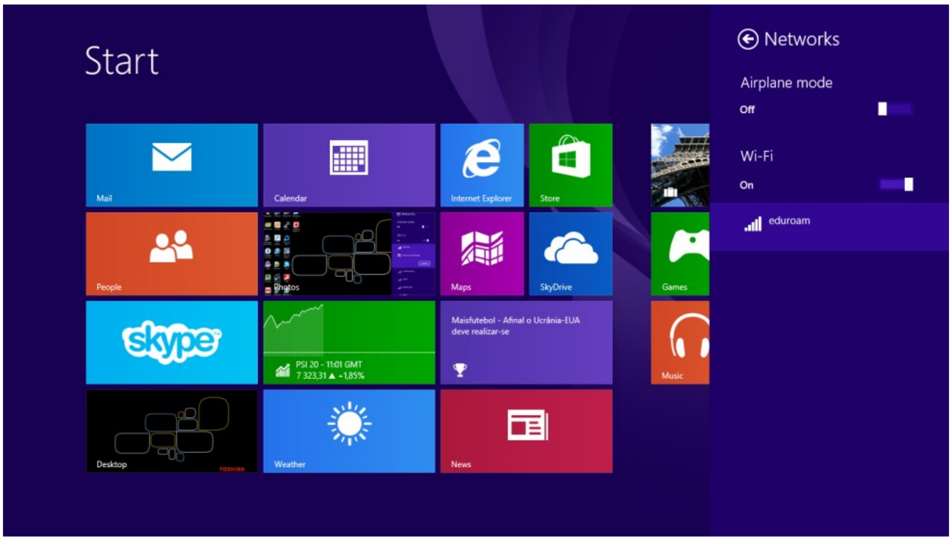
To have wireless connectivity to the Internet you must follow the following steps:

1. Move the mouse to the upper right corner of the monitor to access the sidebar.

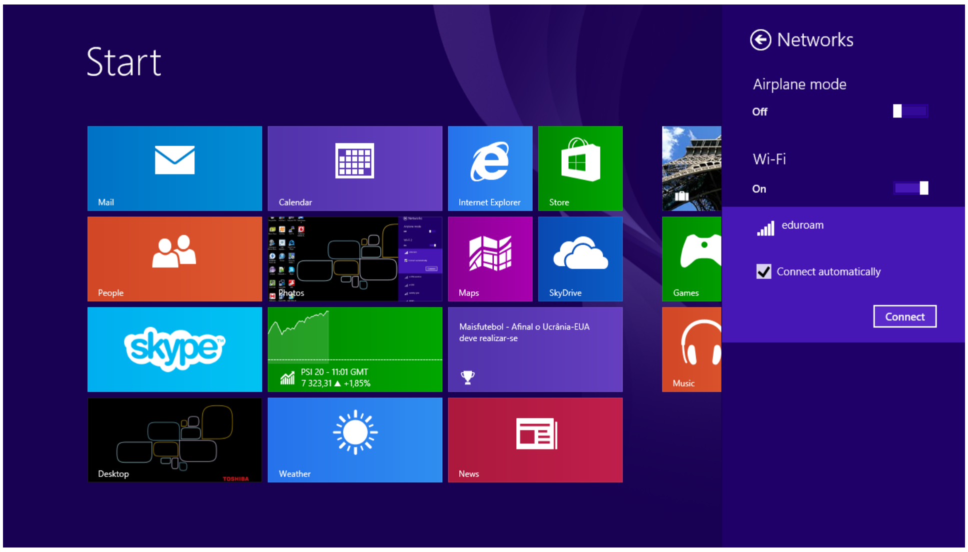
2. Click on '**Settings**'.

3. Click on the '**Available**' icon, represented by a group of vertical bars and an asterisk.

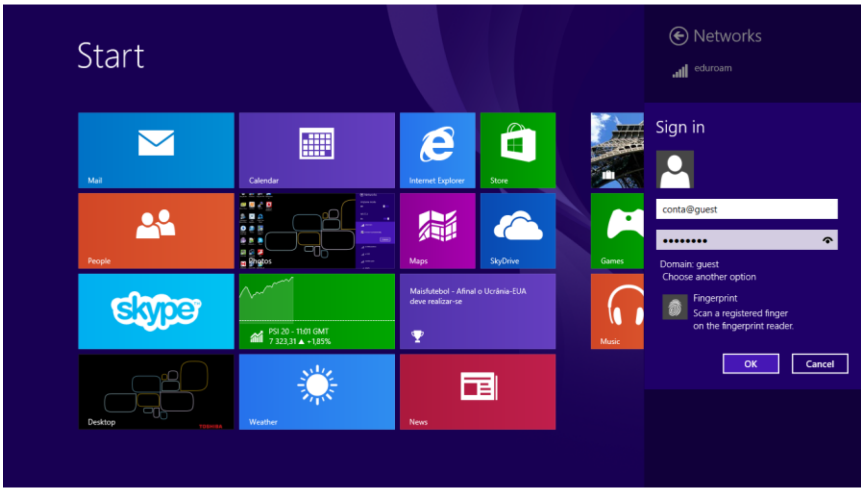
4. Select **eduroam** from the available networks list.



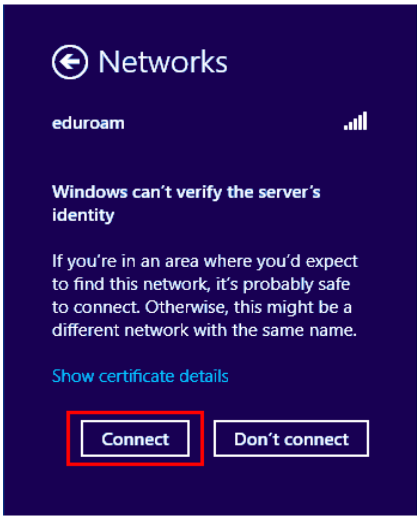
5. Activate the option '**Connect Automatically**' and click on the '**Connect**' button.



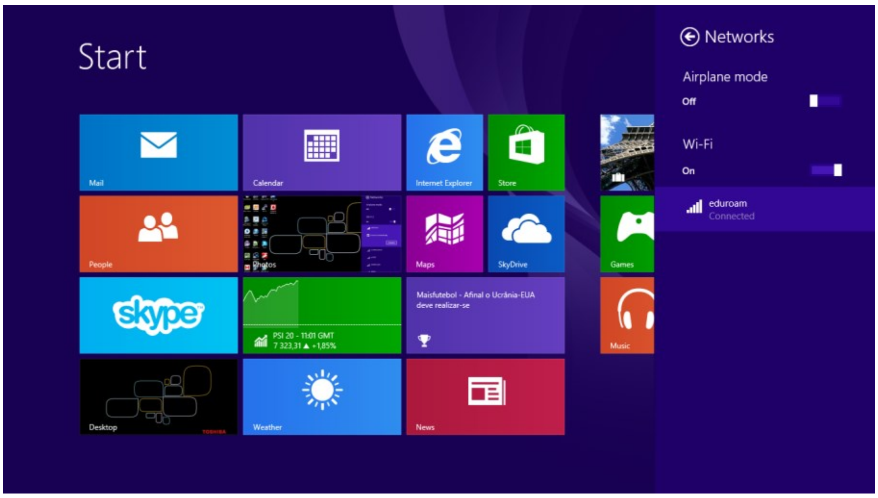
6. Insert your credentials: **username** and **password**.



7. If the following window appears click on '**Connect**'.



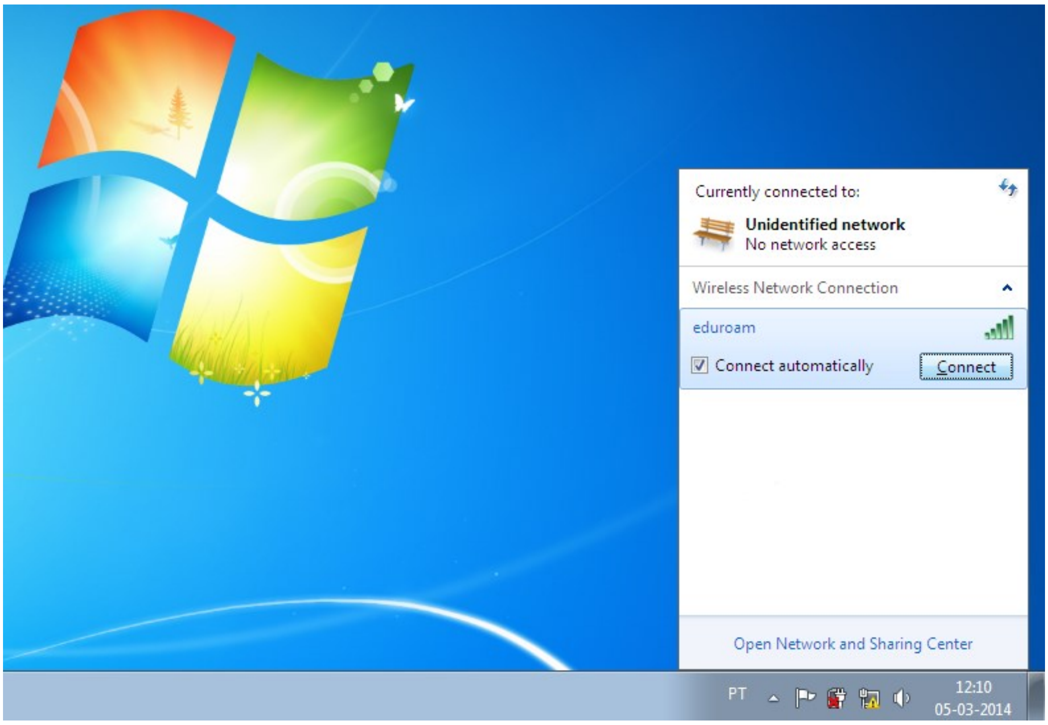
8. If everything is ok, the wireless network connection will be successful.



3. Windows 7

To have wireless connectivity to the Internet you must follow the following steps:

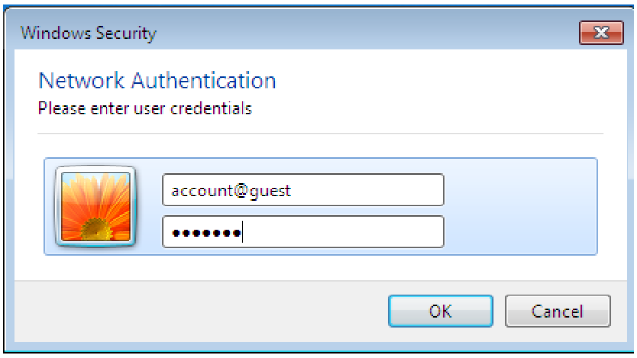
1. In the taskbar, click on the network icon and then click on the '**Connect**' button.



2. In the **Username** field put the account name for the event:

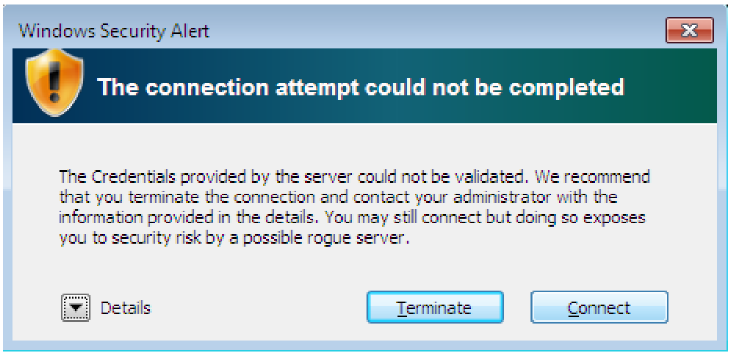
   Example: **account@guest**

   In the **Password** field put the account's password.

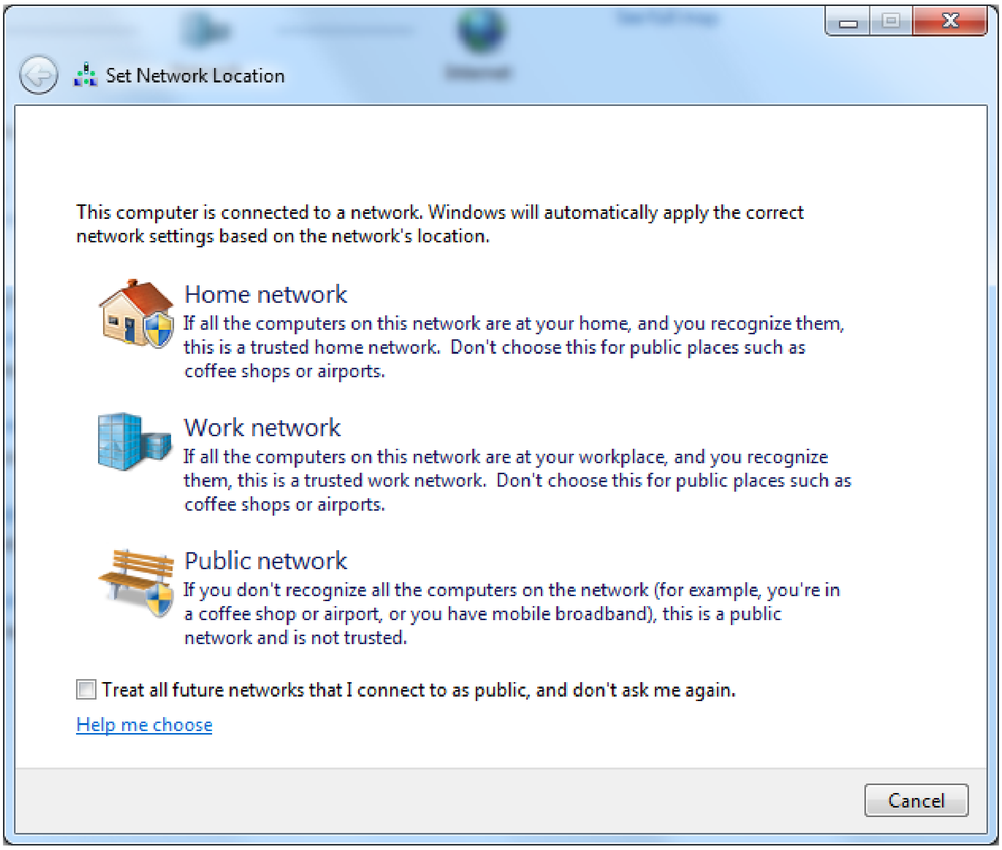


Insert your credentials again if you're asked to.

3. Confirm the server's certificate validity, choosing '**Connect**'.



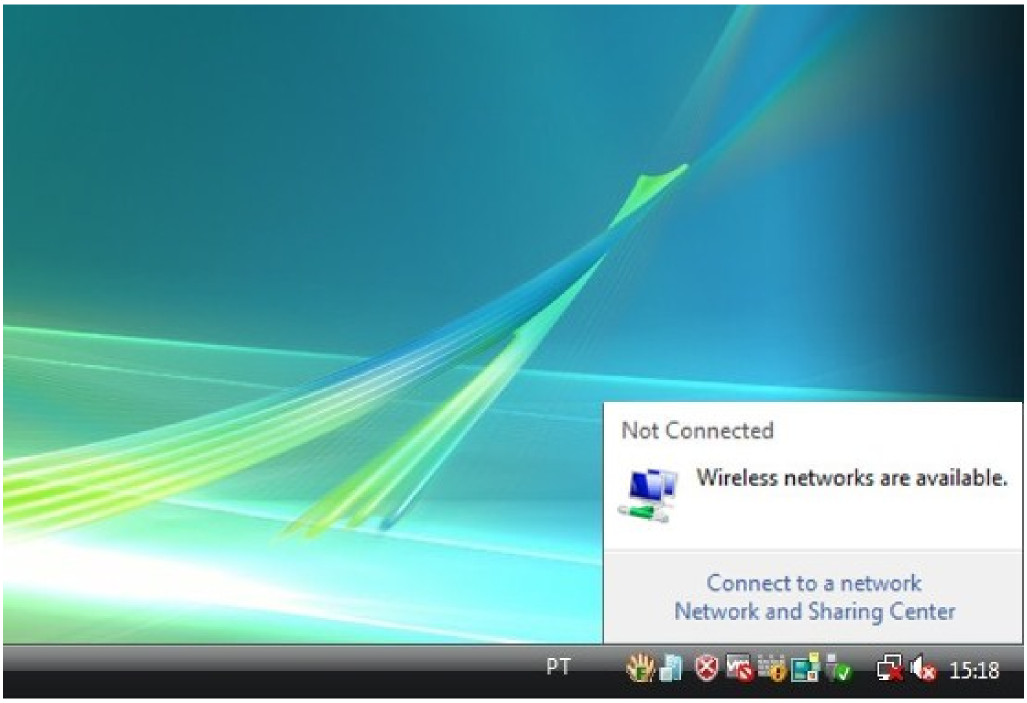
4. Set network location: **Public Network**.



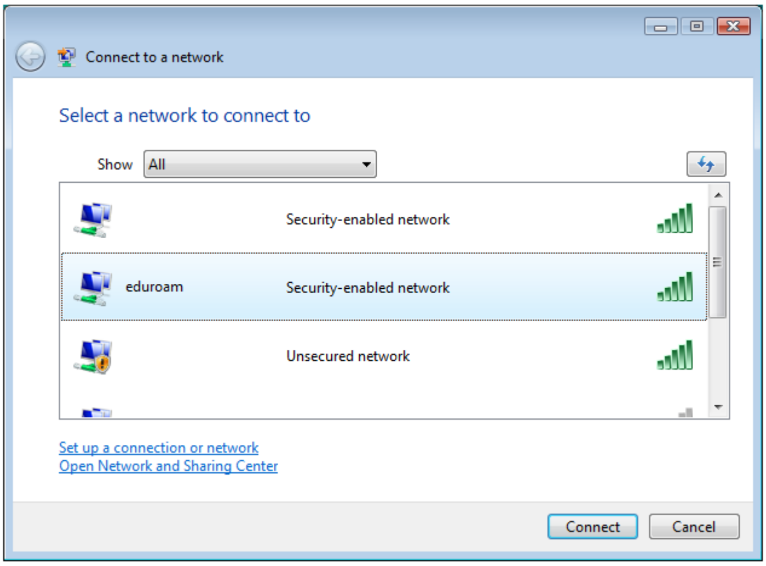
4. Windows Vista

To have wireless connectivity to the Internet you must follow the following steps:

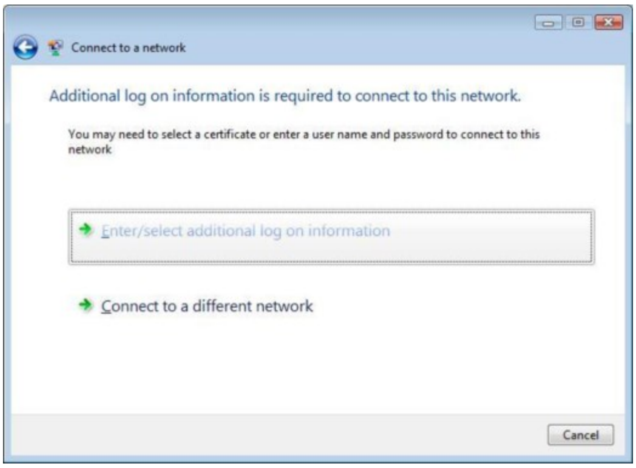
1. In the taskbar, click on the network icon and then click on '**Connect to a network**'.



2. In the '**Connect to a network**' window click on the **eduroam** network. After selecting **eduroam**, click on the '**Connect**' button.



3. Click on '**Enter/select additional log on information**'.



4. In the **Username** field put the account name for the event:

   Example: **account@guest**

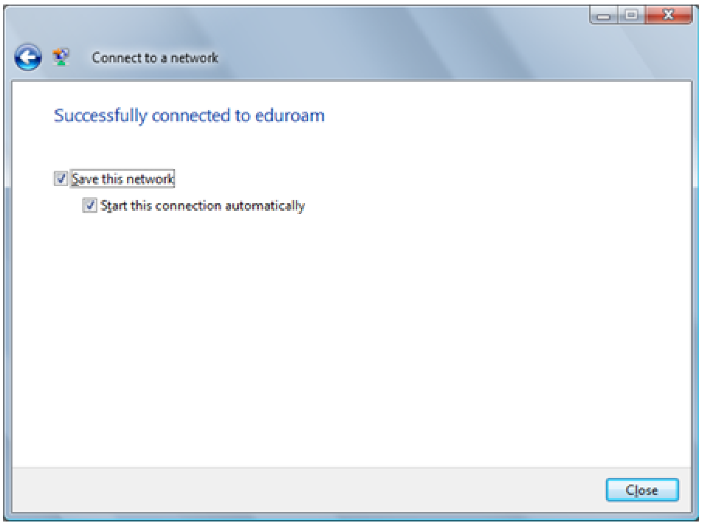
   In the **Password** field put the account's password.

5. Click again on '**Enter/select additional log on information**'.

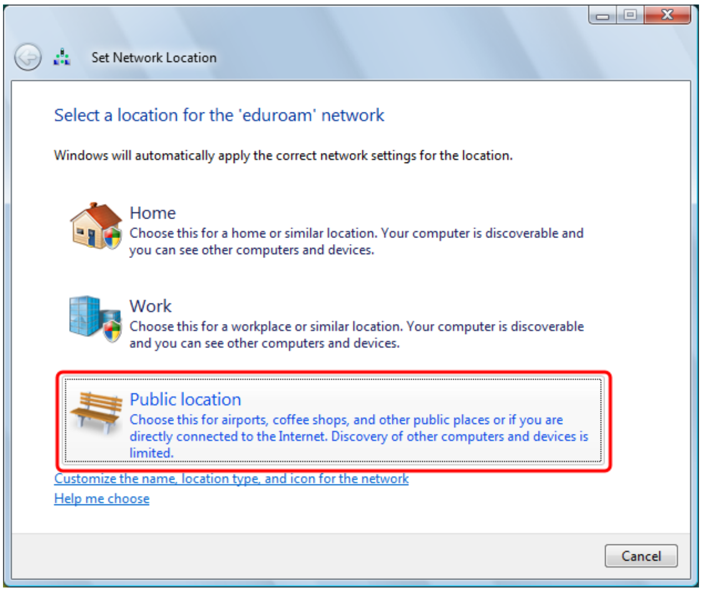
   Insert your credentials again if you're asked to.

6. Confirm the server's certificate validity, choosing '**OK**'.

7. Save your network connection.



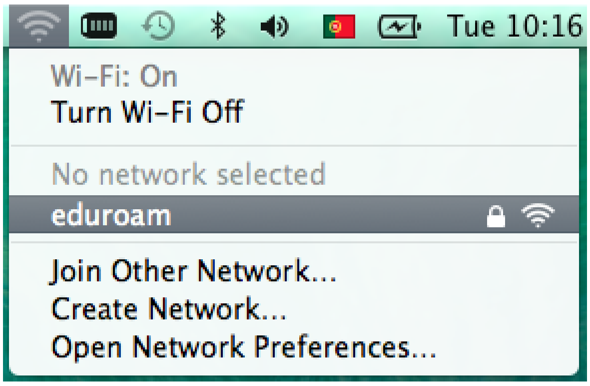
8. Set network location: **Public Network**.



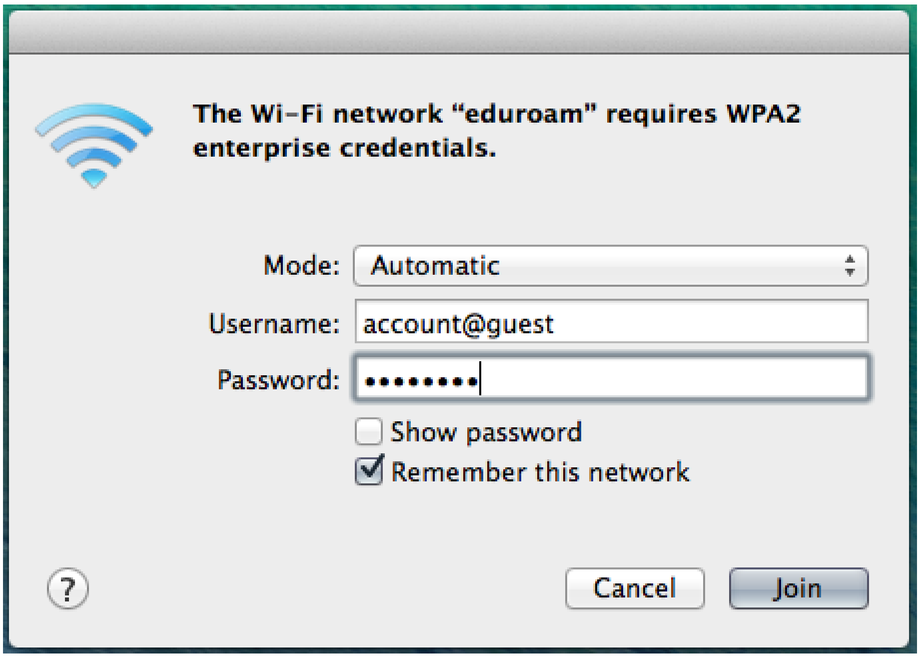
5. MacOS

To have wireless connectivity to the Internet you must follow the following steps:

1. Click on **AirPort**. Select the **eduroam** wireless network.

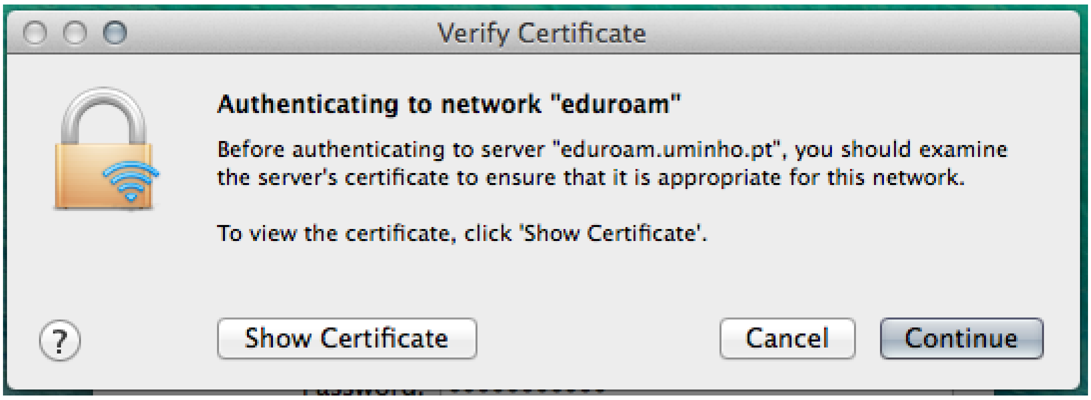


2. The following picture appears. Insert the credentials you were provided: **username** and **password**.

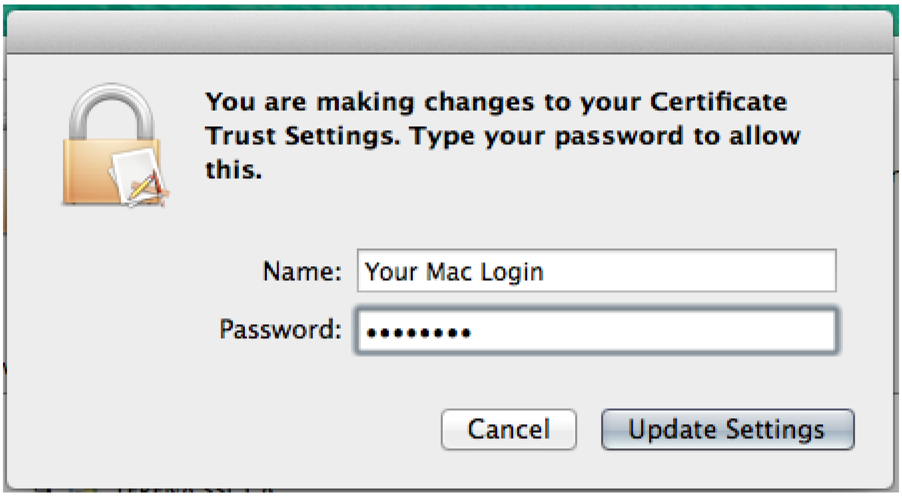


3. Click **Join**.

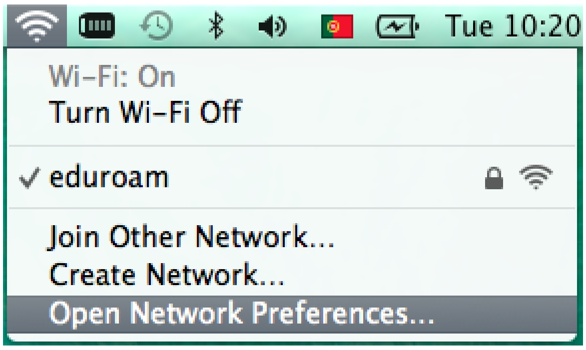
4. If the following dialogue box shows up, click on '**Continue'**.



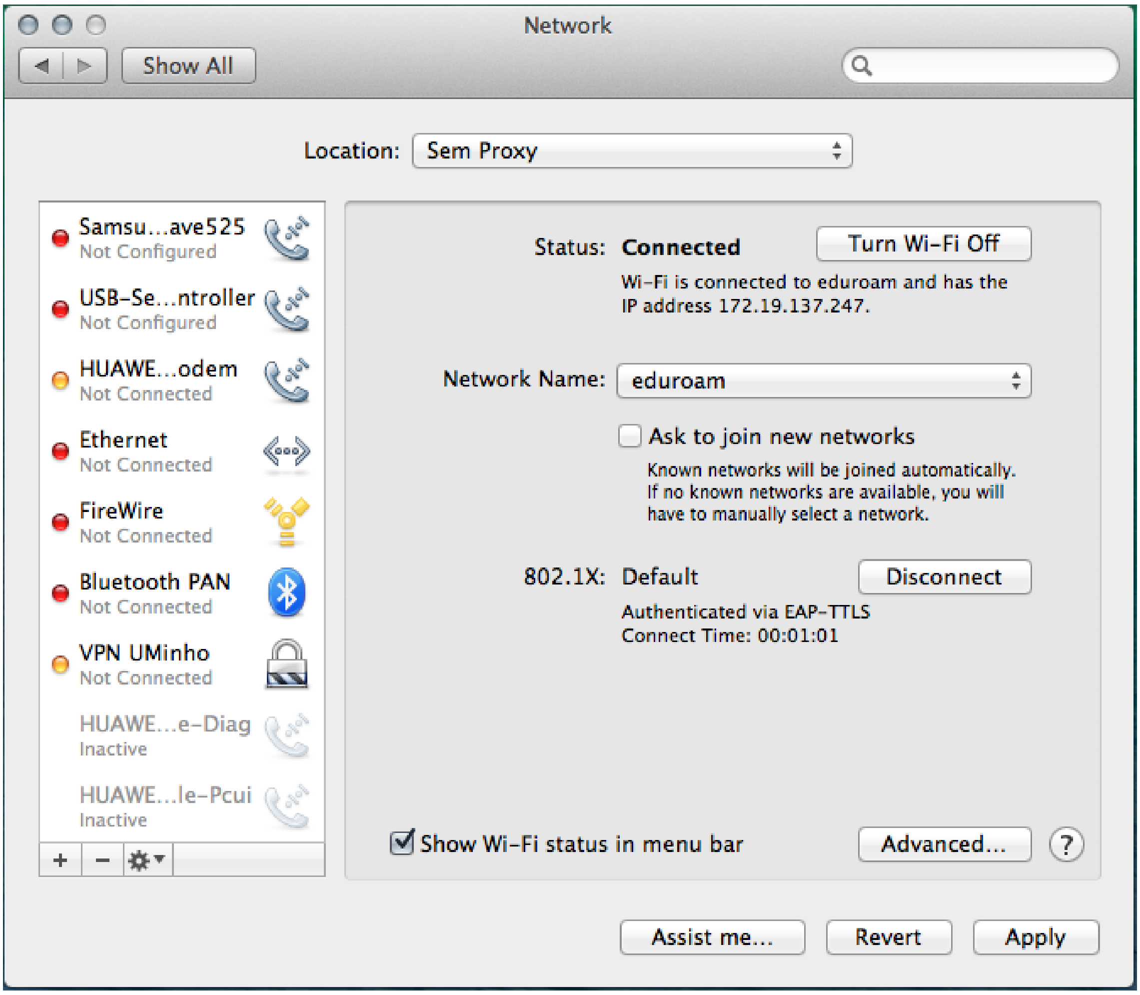
5. Insert the password of your Mac's username and click '**Update Settings**'.



6. Click again on **AirPort**. If all went well, you should see a picture similar to the next one.



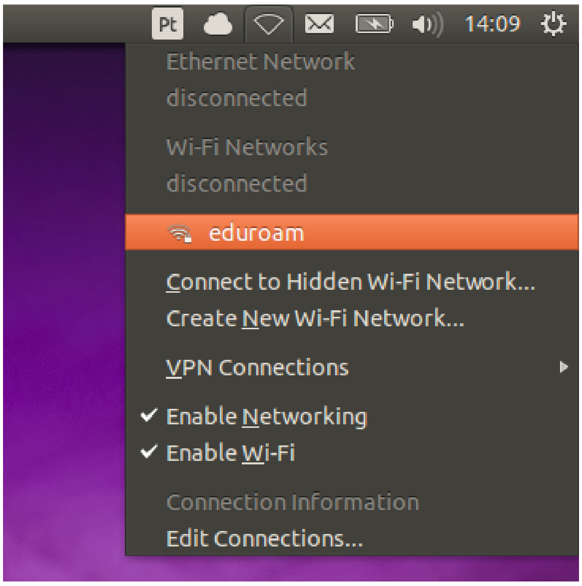
7. If you select '**Open Network Preferences...**', you should see something like the next picture (the IP address must begin with 172.xx.xxx.xxx), meaning that you are connected).



6. Ubuntu

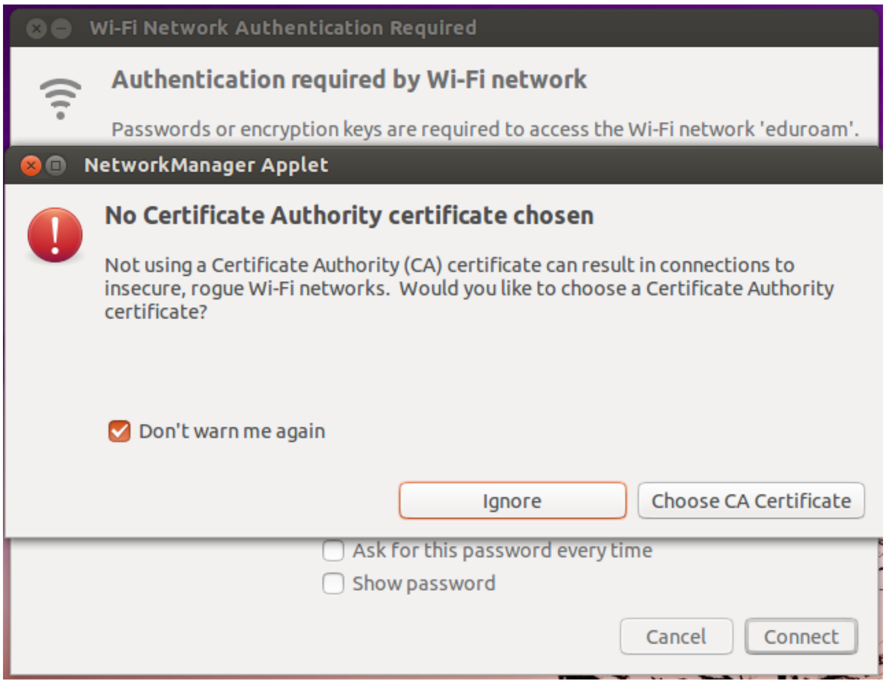
To have wireless connectivity to the Internet you must follow the following steps:

1. Click the network icon and select **eduroam**.



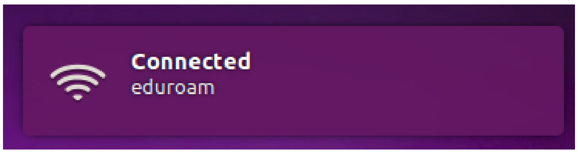
2. The following picture appears. Insert the credentials you were provided: **username** and **password** and click on '**Connect**'.

3. Click on '**Ignore**'.



4. If you're asked again insert the credentials you were provided: **username** and **password** and click on '**Connect**'.

5. It appears the confirmation of a successful connection to **eduroam**.



6. If everything went fine, the connection is now established.