From Natural to Artificial Intelligence: how to use them to achieve sustainable manufacturing

(Progress of Using IA and Sustainability in Arc-based Additive Manufacturing in a Brazilian Research Group)

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28th INTERNATIONAL CONGRESS OF MECHANICAL ENGINEERING

FORWARD

- Thanking for the invitation

- Who am I?

- **Introducing my talk on AI and Sustainability**
  - The educational virtual platforms are examples of the use of AI (background image and external noise reduction) and sustainability (more people having access without consuming more resources).
  - They made communication more efficient and effective.
  - Yet, to some extent
    - This “To some extent” is the emphasis of my speech:
    - Not to deny the importance of AI and Sustainability,
    - but to discuss the use of artificial intelligence rationally
    - and always make a holistic analysis to search for sustainability.

The first question to reflect on is:

Is artificial intelligence something new in manufacturing?

❖ The Background in the relationship between my research and AI and Sustainability

A University West (Sweden) vice-chancellor's motto:

To Be Crazy Enough
(after Martin Hellström)

- I follow such a motto by researching "outside the box", while staying grounded and with an objective.
- At least, I see myself that way (sorry if it sounds like bragging, but I want to raise a point: Is artificial intelligence in Manufacturing only a fashion?)

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❖ The Background in the relationship between my research and AI and Sustainability …

- In the 2000s, teaching classes with the help of digital technologies

SCOTTI, Américo. Increasing Welding Learning Effectiveness by Laboratory Classes Assisted with Non-passive Audio-visual. Soldagem & Inspeção, 22(3), 2017

- Following, my colleagues and I worked with students to explore the concept of providing remote welded fabrication assistance, where an expert could support staff on the shop floor:
  - An operator using a microphone, a camera, a data acquisition card, and a modem to transmit images, data, and sounds.
  - An expert could help an operator far away (such as in the Amazon region) efficiently regulate the welding machine, without being physically present or incurring high costs.
- We successfully tested the system inside the university, between two buildings, …
  - but at that time, we could not go easily beyond the university walls (sound and images were transmitted through VoIP (Voice over Internet Protocol)

❖ Why has this talk been extended for so long on a non-related matter?

- Virtual Communication is a niche to talk about AI and Sustainability
- Virtual Communication has evolved a lot in a few years, with "intelligent" resources:
  - Noise elimination
  - balancing the intensity of voices and lighting
  - backgrounds, etc.
- Sustainability is also present in this evolution:
  - less displacement of people, with a reduction of carbon emissions, among others.

- In my opinion, it was in Virtual Communication that the so-called AI developed faster and became more popular.
  - With the emergence of the generative artificial intelligence;

- Returning to the invitation to give this lecture, I feel somewhat uncomfortable, as I am not an AI developer or a sustainability expert (I am a user, only).

- So, forgive me if I approach the lecture with a somewhat philosophical and personal bias, even though I am not a philosopher.
  - But the maxim of the “school of life” applies in this case. Throughout my 70 years of survival.

The topic of my speech is on how to use IA to achieve sustainable manufacturing

- I believe that I need to start from how I define Artificial Intelligence and Sustainability in the context of my research (the personal side of the speech).

- Therefore, I need to narrow the definition of AI and Sustainability.
  - There will be several other definitions by others.
- Let´s begin with how I see the difference between Natural and Artificial Intelligence

❖ Intelligence

- What would Intelligence be?

My answer: The ability to process information to use it to address a problem.

- Would Intelligence be an innate thing?

My answer: Yes, intelligence is a gift to human beings. But intelligence must be developed and cultivated

❖ Natural Intelligence

How to develop one's own intelligence?

- By observation
  - knowledge (possession of information)
  - wisdom (ability to use knowledge)
- Data collection
  - Study and research
  - Experience
  - Formation of a behavioural model
- Motivation
  - Interests (economic, ideological, cultural, etc.)
- Discernment and Judgment:
  - influence of the environment (people and conditions)
  - Rationalization and emotionality.
  - Allows improvement in not making the same mistakes

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❖ Natural Intelligence …

So, to develop intelligence is complex and demands an interconnected relationship

- A neural network

- Of which weights are given by the parameters of discernment
    - which are limited by motivation
    - and are shaped by obtaining data over time (research, experience, and behavioral model)
    - which comes from knowledge and wisdom (obtained by observation)
        - Knowledge alone does not guarantee correct decision-making or effective application.
        - Wisdom allows one to make more assertive decisions and solve problems more effectively.

❖ Artificial Intelligence x Natural Intelligence

- Would artificial intelligence (AI) be intelligence?

My answer: Yes. Data is also observed and collected. It is conditioned by motivation. However, it is debatable that AI has discernment.

What about machine learning?

My answer: Machine learning is a way of developing discernment to avoid making the same mistakes.

Would Automation also be Artificial Intelligence?

Automation also stems from models (stochastic or deterministic), created from observations (sensors) and collected data (model generation and validation). They may also have algorithms that make discernments to some extent. For me, automation = AI + hardware.

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The topic of my speech is on how to use IA to achieve sustainable manufacturing

- Let´s move to how I see sustainability applied in manufacturing

❖ What is sustainability?

- Sustainability is to "meet the needs of the present without compromising the ability of future generations to meet their own needs“ (The United Nations' 1987 Brundtland Report)

- Or “sustainability is the ability for something to continue over a long period of time by maintaining a balance across three key dimensions:
    - Environmental Sustainability (natural resources and protecting ecosystems)
    - Social Sustainability (social equity, well-being, and cohesion for all people)
    - Economic Sustainability (Maintaining an economy that supports a defined level of economic production and prosperity indefinitely)

However, the first thing that would come to our mind is “environmental sustainability”

❖ Is Additive Manufacturing an environmentally sustainable production technology?

One could say yes, given the reduced material waste.

❖ Is the production of wires, rods, and powders economically effective, not affecting the environment, and of predicted infinite prosperity?

Not all aspects of sustainability will be addressed in this discussion.

I prefer to pull the thread of Goal 12 of the United Nations 2030 Agenda for Sustainable Development:

- the commitment to making fundamental changes in the way that our societies produce (and consume) goods and services.

Let´s focus on the business sector and individuals aiming at changing unsustainable consumption and production patterns, as well as technological and innovative capacities to shift toward more sustainable patterns of production.

- Majority of the work is on manufacturing industry sustainability, mainly concerning the lifecycle of produced goods…
    - … while mostly leaving unaddressed the implementation aspects.

- We need to make the manufacturing industry more sustainable, resilient, and innovative to maximize benefits for society and the economy.

- Which brings out the three pillars of the ESG (Environmental, Social, and Governance) good practices
    - The objective of ESG is to encourage companies to adopt sustainable and ethical practices in all areas of their operation, benefiting not only the environment and society, but also generating value for shareholders and ensuring the long-term sustainability of the business.

Do the concepts of Sustainability and ESG apply to small businesses?

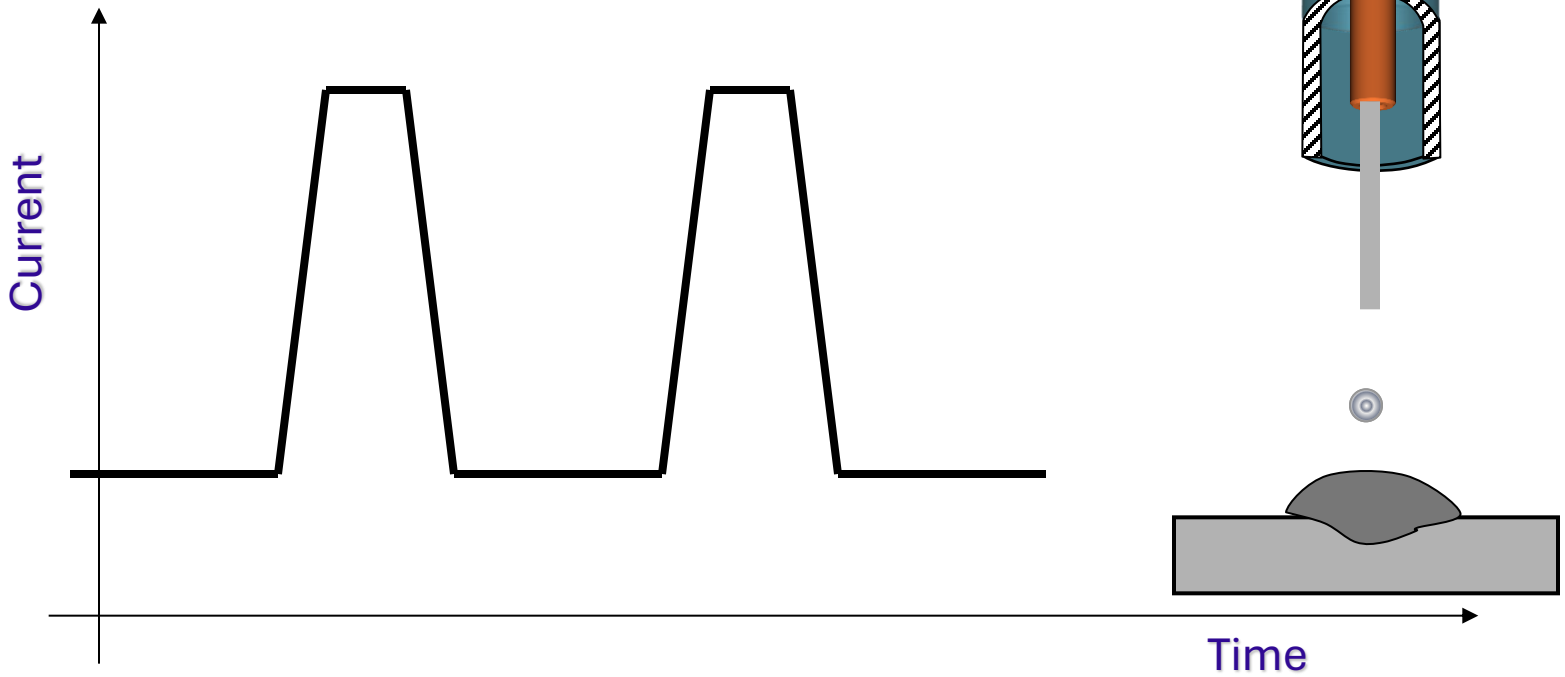
My answer: Yes, an entrepreneur must plan the activities to be sustainable, not only from an environmental point of view, but also economically (for instance, an idea for a startup must sustain prosperity indefinitely).

Examples of Using IA and Sustainability in Manufacturing by our Brazilian Research Group

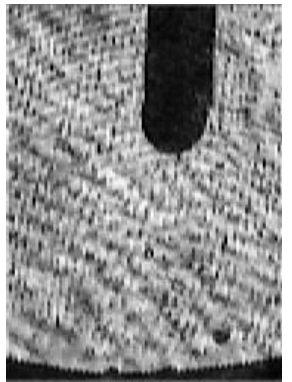
Case 1 – Pattern Recognition

The use of pulsed current in the Gas Metal Arc Welding process has several advantages

The principle is to control the metal transfer



The desirable is a droplet per pulse (ODPP) at the end of the pulse



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- However, for each shielding gas composition, and wire composition, diameter and free extension, there will be a set of pulsing parameters to reach the condition of ODPP at the end of the pulse;

- And, in practical conditions, to see the droplets transferring is not possible;

- As a solution, the power source manufacturers elaborated on laboratory parameters for the most popular consumable combinations, using sophisticated resources (including high-speed cameras);

- However, shielding gas compositions, wire compositions, and free extensions are variable for many reasons.

- Consequently, end-users could hardly set their parameters on an optimal basis (and still cannot)

- In April 2002, a PhD thesis was defended to demonstrate that it is possible to determine online and control the ODPP at the end of the condition without using a high-speed camera and laser backlighting, making it feasible to set optimum parameters for all gas-wire combinations.

“Recognition and Control of Metal Transfer in Pulsed MIG/MAG Process", Dr. Eng. Thesis, Universidade Federal de Uberlândia, 05 de Abril de 2002.

US Patent 2004/0034608 A1, de 19/04/2004, com International Publication Number WO 03/082508 A2, de 09/10/2003, titular: Praxair Technology, sob o título "Luminescence Sensing System for Welding", inventores: de Hélio Cordeiro de Miranda, Valtair Antonio Ferraresi e Américo Scotti

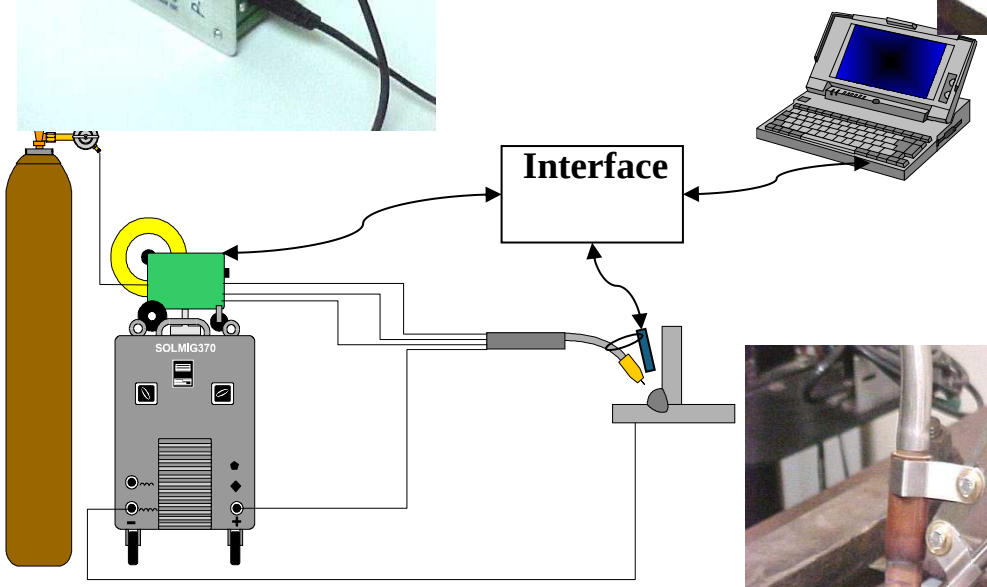
MIRANDA, H.C.; SCOTTI, A.; FERRARESI, V.A., Identification and control of metal transfer in pulsed GMAW using optical sensor, Science and Technology of Welding & Joining, 12(3), 2007, pp. 249-257 (DOI: 10.1179/174329307X164229)

- The principle was based on the shapes of the arc luminescence signal according to the transfer condition (<ODPP, >ODDP, ODPP after the pulse, ODPP at the beginning/middle of the Pulse, and ODPP at the and of the pulse)

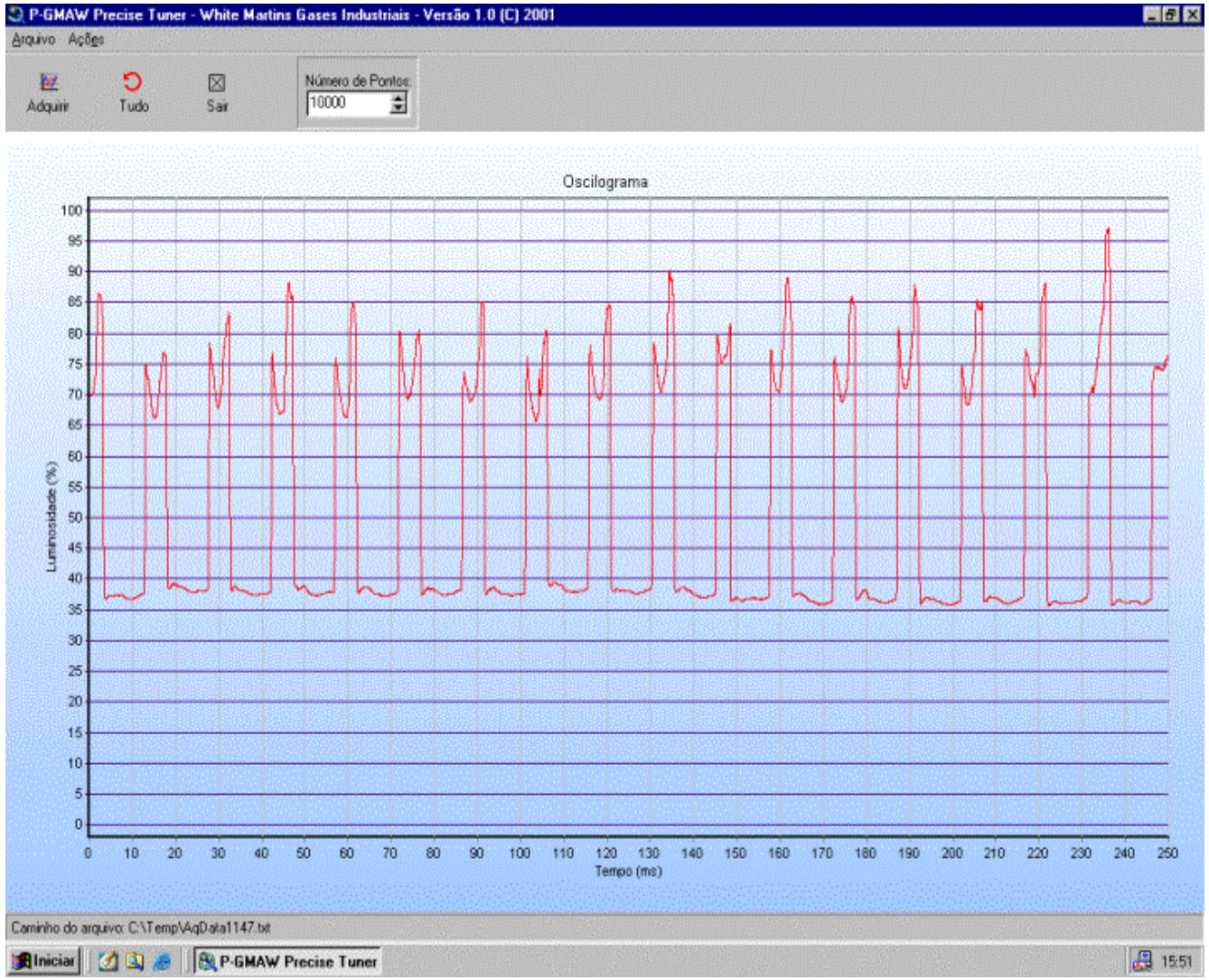
- As each transfer condition produced a pattern of luminescence signal, a neural network algorithm was developed to recognize each pattern and change the pulse parameters in the power source to always keep the optimum “ODPP at the end of the pulse” condition.


P-GMAW PRECISE TUNER
WHITE MARTINS


MOTOMAN SK6

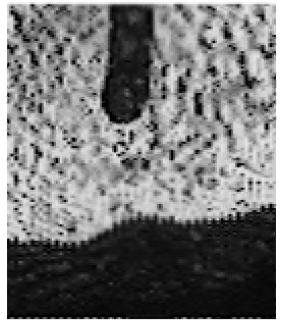

Interface
SOLMIG370

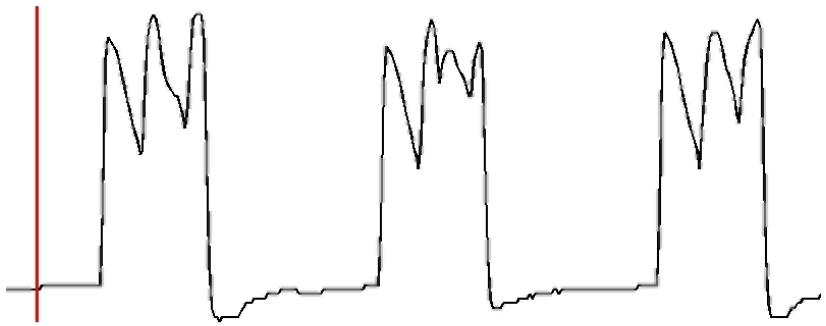
Pulsed Transfer Monitor in MIG



Pulsed Transfer Control in MIG/MAG in action

- **Control in action when more than one drop occurs**





Examples of Using IA and Sustainability in Manufacturing by our Brazilian Research Group

Case 2 – A Smart Trajectory Planning for Wire Arc Additive Manufacturing) (IA)

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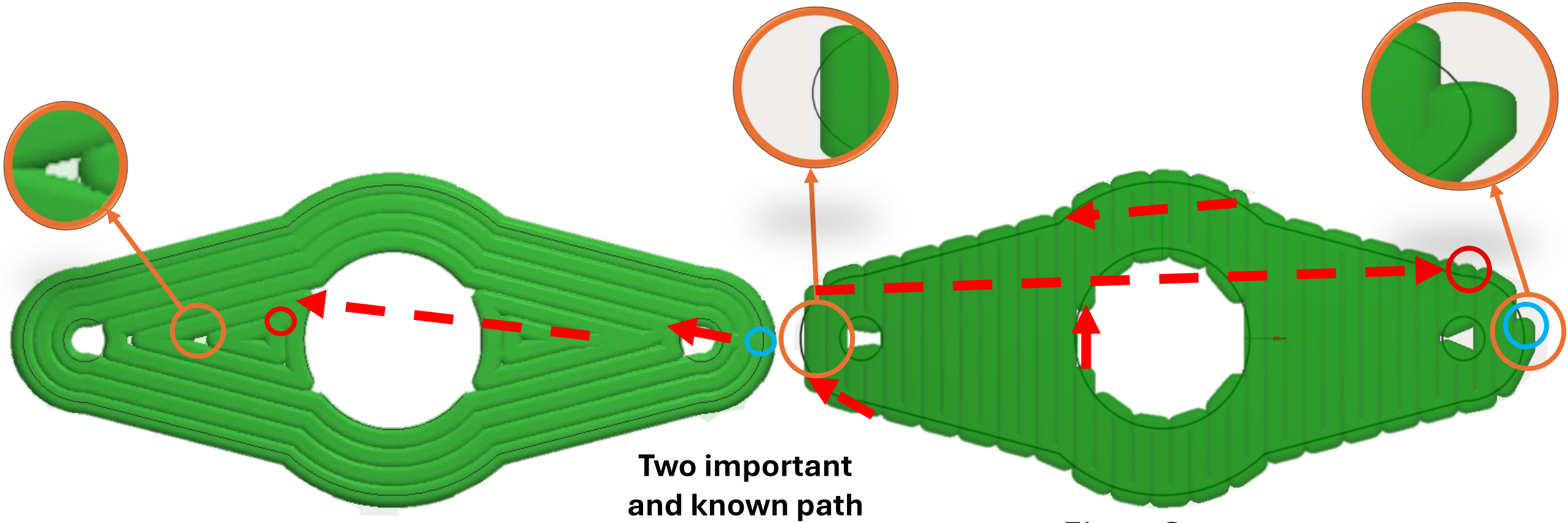
Examples of Using IA and Sustainability in Manufacturing by our Brazilian Research Group

Case 2 – A Smart Trajectory Planning for Wire Arc Additive Manufacturing) (IA)

Contextualization

Path planning has an important role in getting a successful printing.

But conventional strategies may lead to unfilled regions…



Contour-Parallel Strategy

Two important and known path planning strategies

Zigzag Strategy

Start End Non-deposition movements

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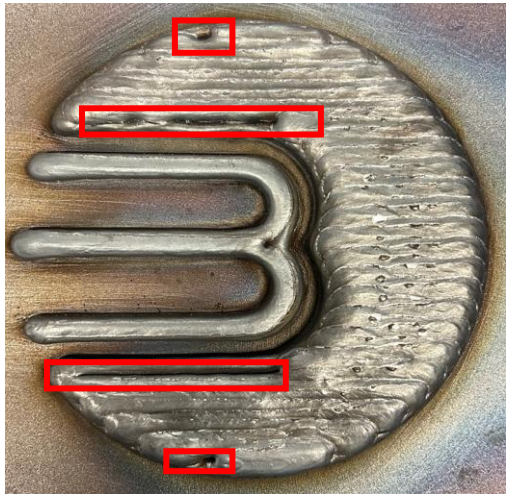
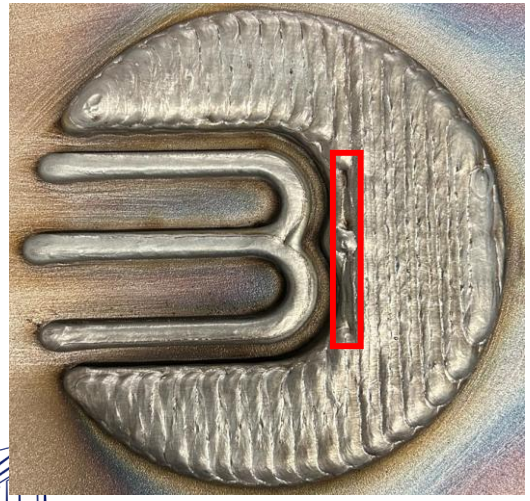
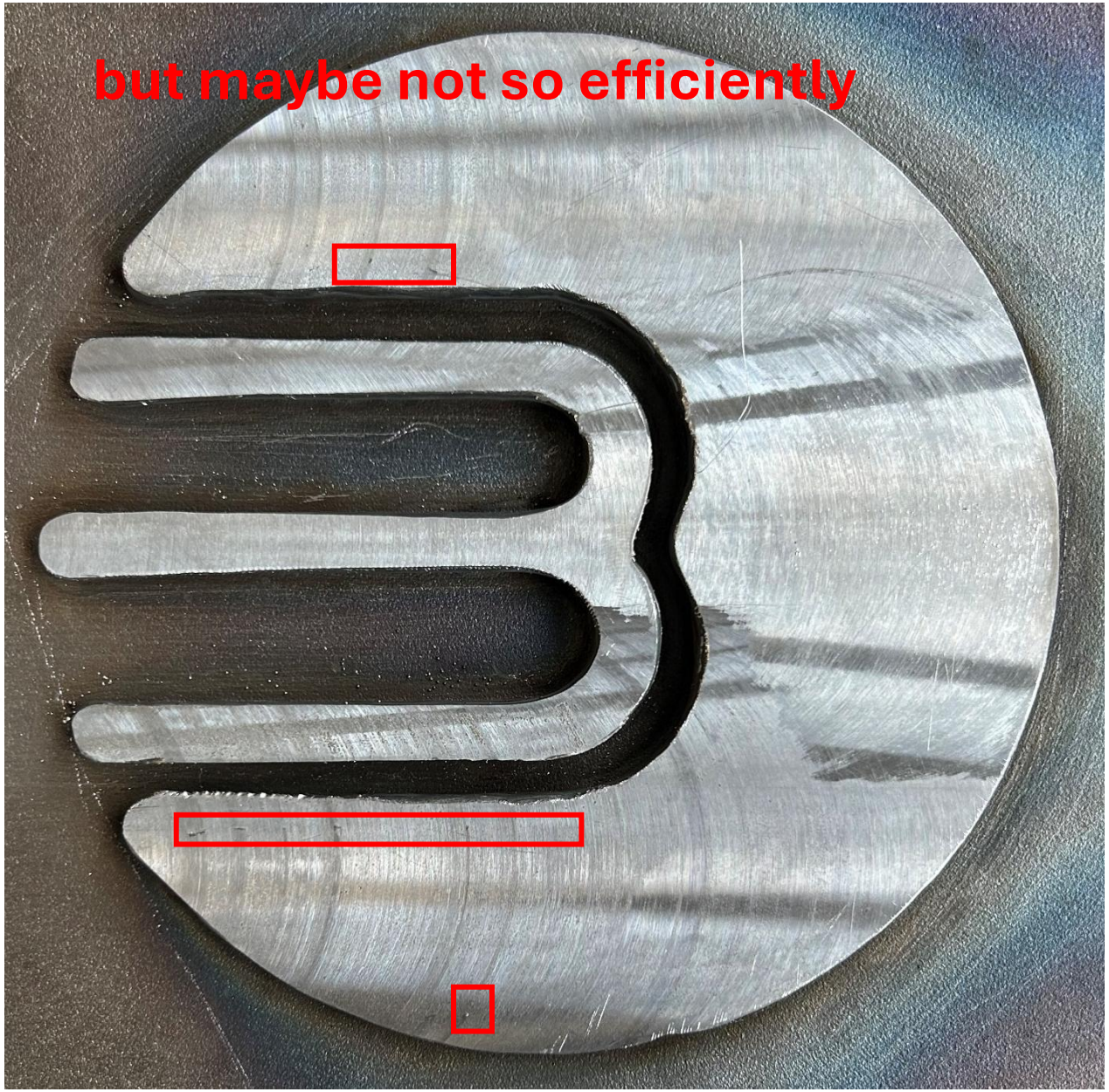
There are practical solutions to minimize the problems, such as rotation between layers usually corrects the unfilled problem, ...



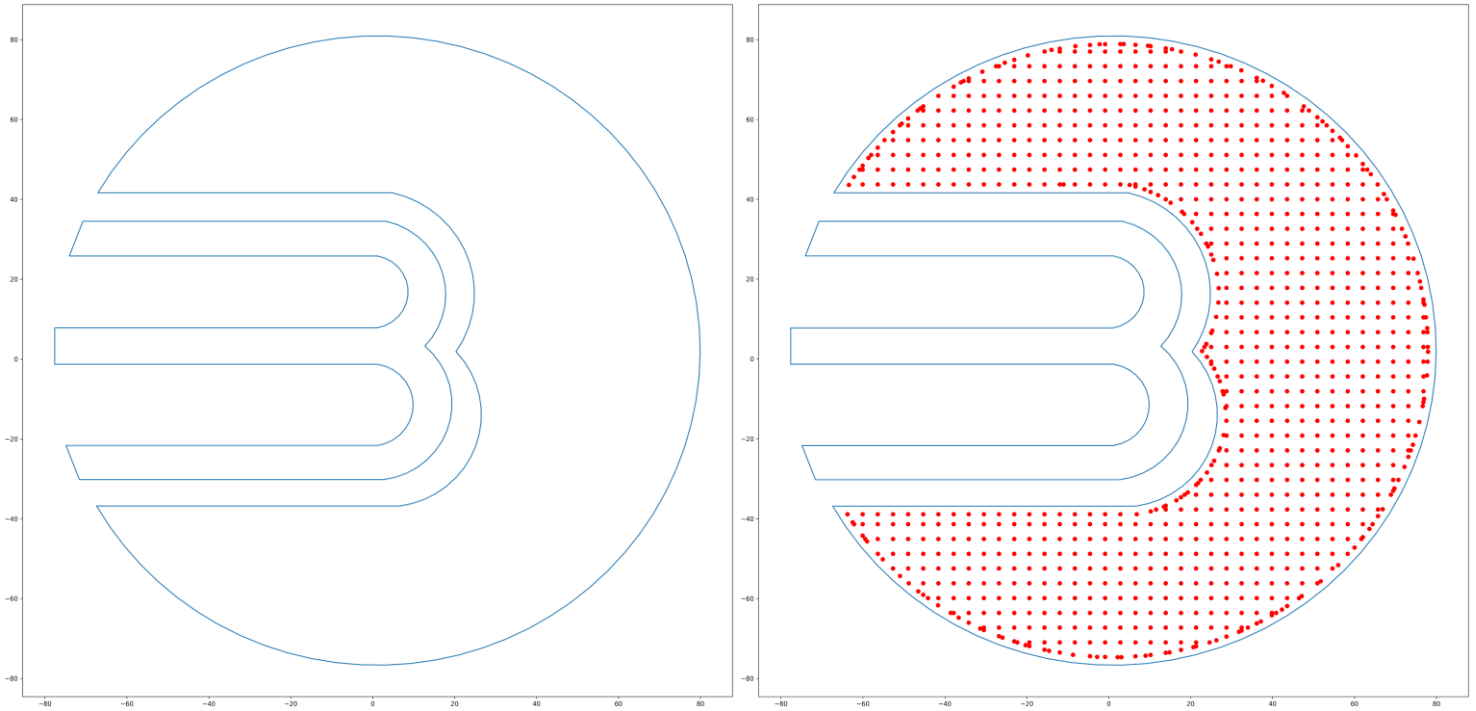
First Layer



Fourth Layer



One solution found by our research group was the Pixel strategy.



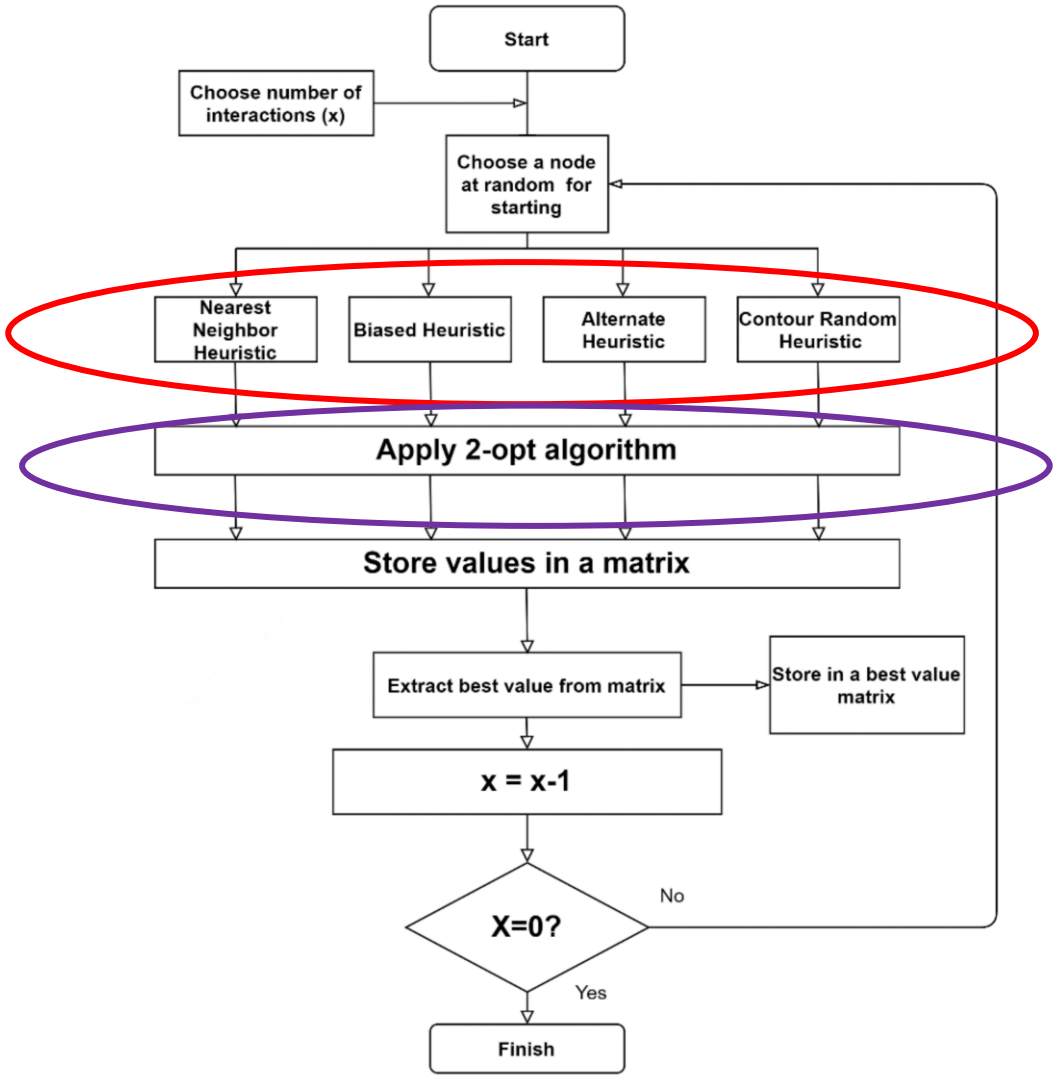
Contour Layer

Pixel Nodes

Pixel is a filling-continuous approach for strategy based on discrete movements, where the end of the trajectory is a neighbour of the start.

Pixel strategy is driven by combinatorial optimization algorithms, using different heuristics (learning from their own experiences) and a local search algorithm.

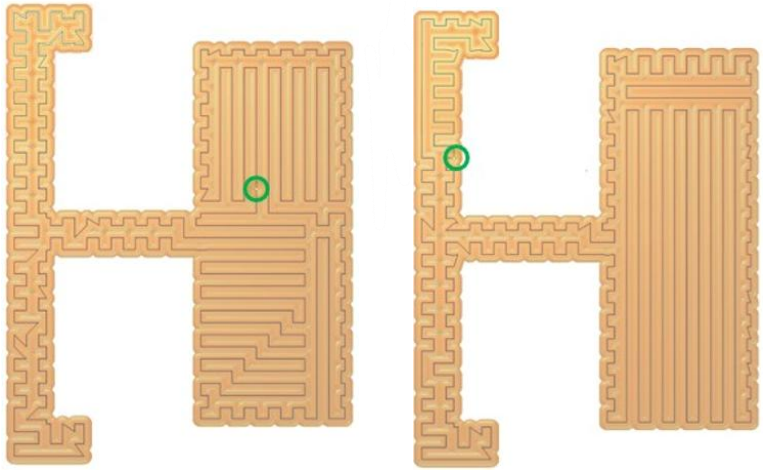
- The Traveling salesman problems (TSP), i.e., of a salesperson that must visit all sites without repeating any and return to the start city, using the shortest trajectory, defines the game rules for all heuristics to solve the problem.



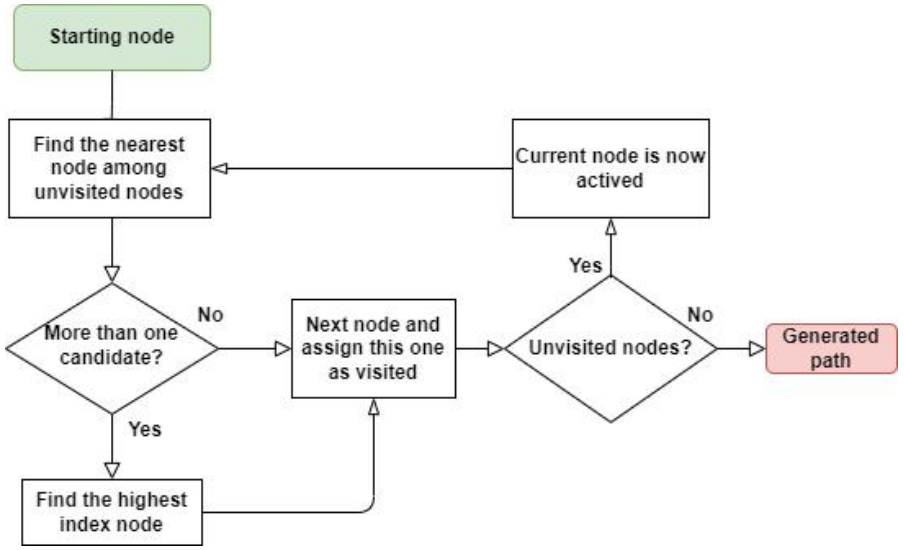
See more at: FERREIRA, RP; SCOTTI, A. The Concept of a Novel Path Planning Strategy for Wire + Arc Additive Manufacturing of Bulky Parts: PIXEL. Metals. Doi: 10.3390/met11030498 and at FERREIRA, RP; VILARINHO, LO; SCOTTI, A. Development and Implementation of a Software for Wire Arc Additive Manufacturing Preprocessing Planning: Trajectory Planning and Machine Code Generation, Welding in the World, 66, 2022: 455–470, doi.org/10.1007/s40194-021-01233-w

Continued improvements were developed: the version Enhanced-Pixel

1) Incorporated the 2-opt **closed**-loop in the algorithm



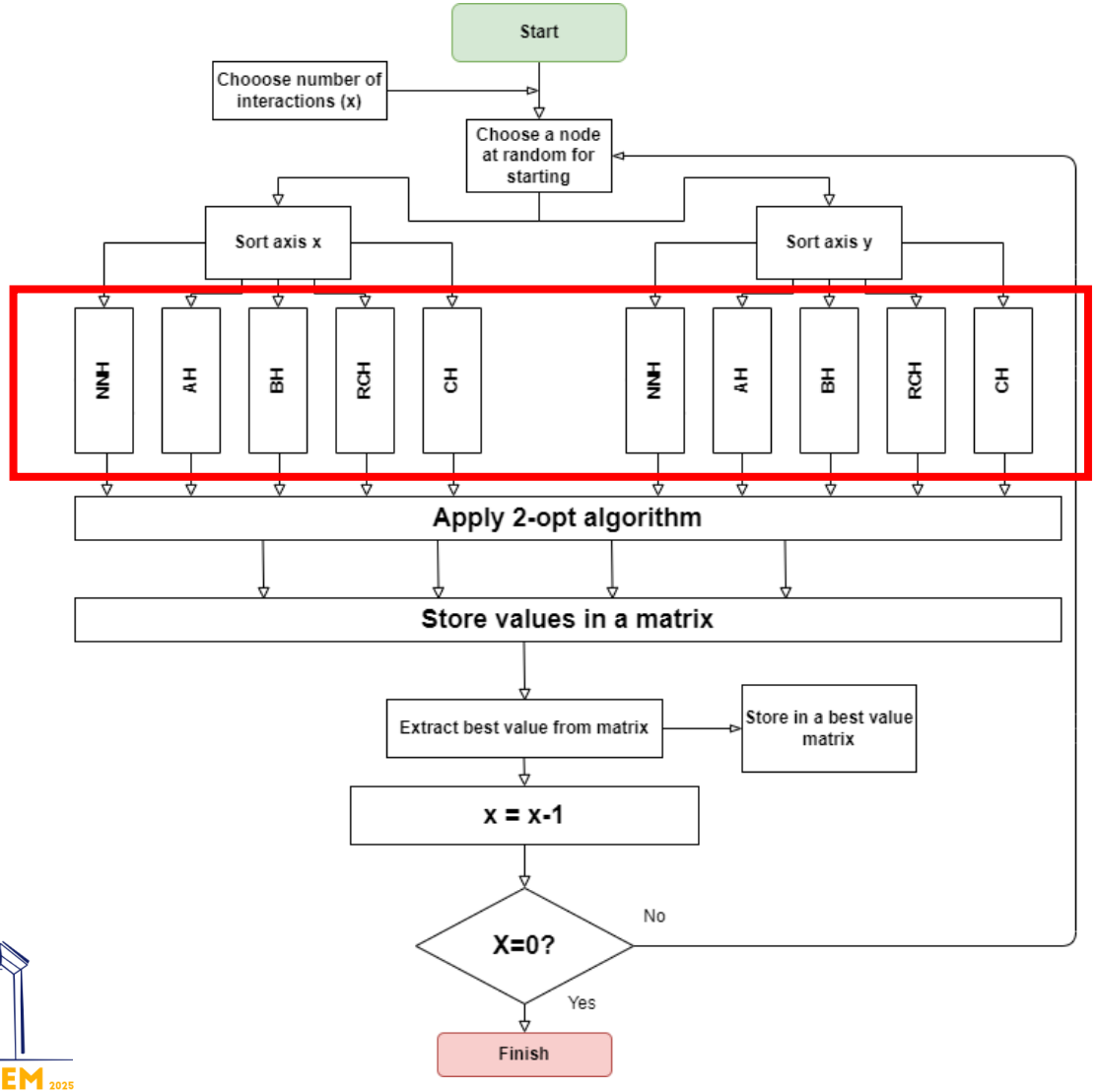
2) The introduction of a complementary trajectory planning heuristic

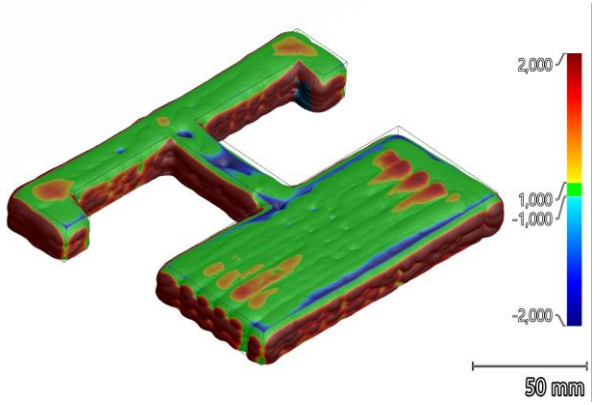


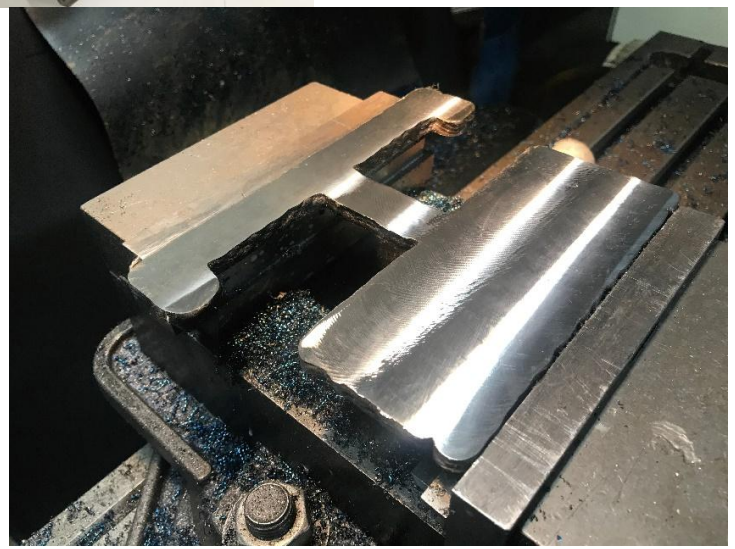
See more at: FERREIRA, RP; VILARINHO, LO, SCOTTI, A. Enhanced-Pixel Strategy for Wire Arc Additive Manufacturing Trajectory Planning: operational efficiency and effectiveness analyses (submitted for publication)

However, the GRASP metaheuristic representing the Enhanced-Pixel strategy shows another kind of setback, i.e., a significant number of iterations.

A clever solution was needed…







Root for the solution:

Machining learning

Reinforcement Learning was the Machine Learning method focus of this work.

- Reinforcement Learning method works on interacting with the environment, whereas the supervised learning method works on given sample data or examples.
  - Neural network, for instance, is a supervised method
- One should not use Reinforcement Learning when there is enough data to solve the problem

Root for the solution: The Multi-Armed Bandit Problem (*a Reinforcement Learning approach*) was found as the best tool to reduce the number of iteration

Basically, imagine a gambler in a row of slot machines (one or more machines are biased). He/she must decide which machines to play, how many times to play each machine, and in which order to play them, and **whether to continue with the current machine or try a different machine (a dilemma)**.

The dilemma is solved by the balance of both:

Exploration is understood here as a process of searching for new information (such as the gambler testing several machines);

Exploitation is understood as a process of working with known information (such as the gambler investing in the machine that he/she knows giving the best results).

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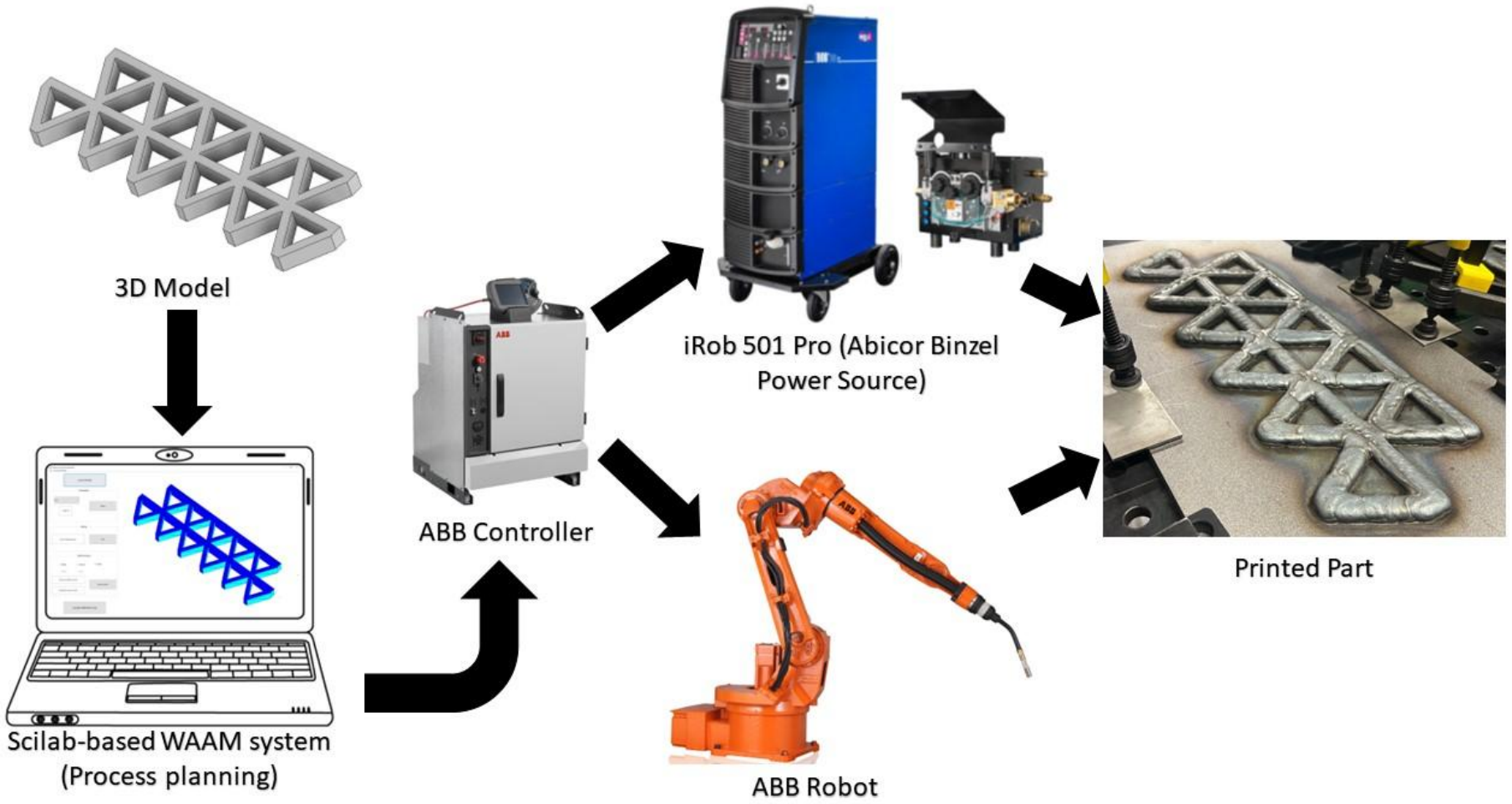
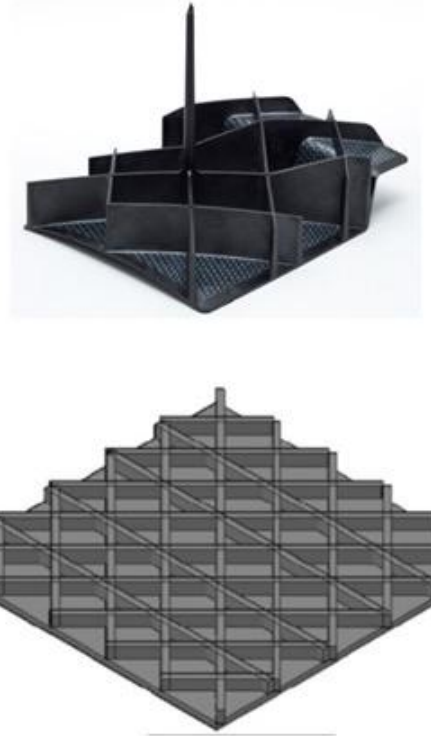
Several tests were implemented (computationally, to assess processing time gain, and experimentally, to assess the performance)

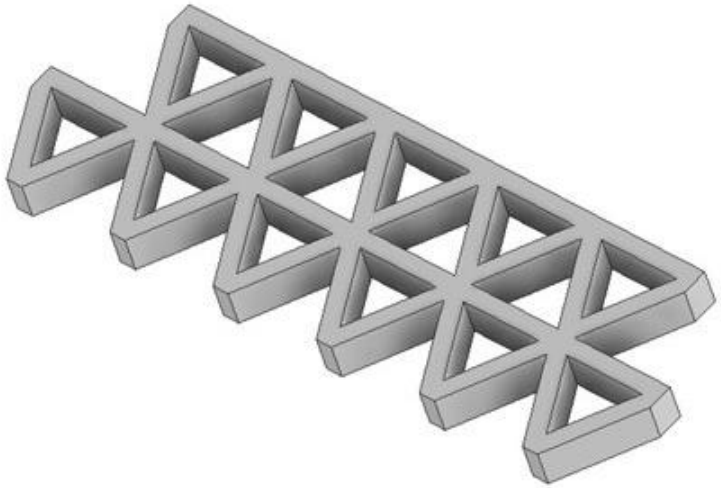


A pilot application: a stiffened panel

There were 3,000 nodes, 20 iterations.



Grid stiffened panels



3D Model

Printed Part

Advanced-Pixel converged in most cases to short trajectory distances and building times with fewer iterations than the previous version of the strategy (Enhanced-Pixel)

Examples of Using IA and Sustainability in Manufacturing by our Brazilian Research Group

Case 3 – A Business Plan for a startup to build parts (Economic Sustainability)

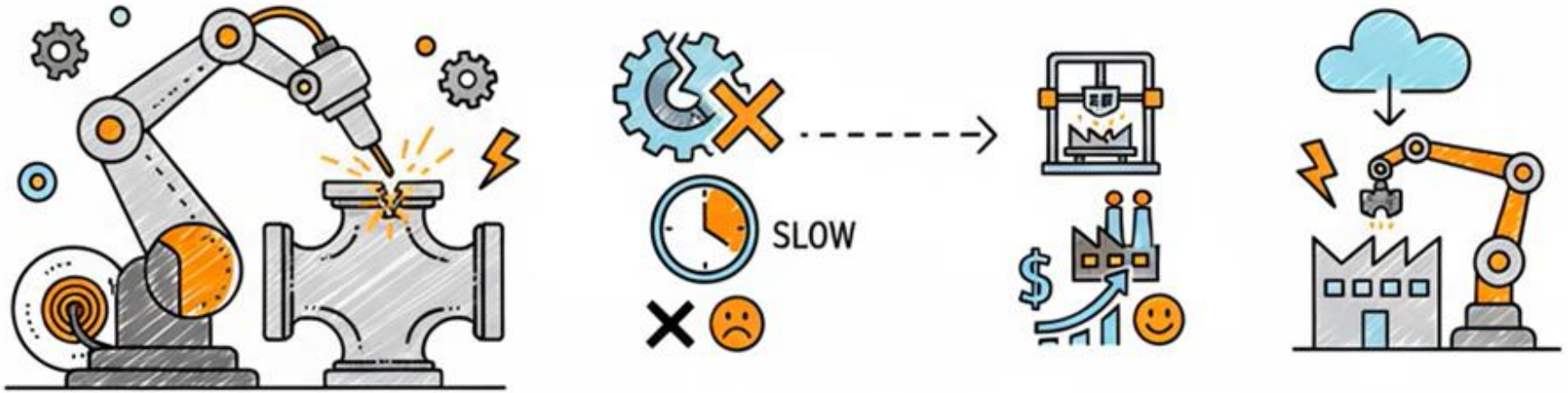
Students were motivated to elaborate on a Startup to produce using WAAM

- The first question brought to them?
  - Is WAAM a mature technology to attract industry? Why not?

- The guidance was: The differential of this startup must be the search for economic sustainability, based on innovation to reduce manufacturing costs.

- Back to the beginning of the speech, allow me to use AI to present this idea:

The Future of Manufacturing



Thanks, for your kind attention.

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