UNIVERSITÉ DU LUXEMBOURG

INTERVENANTS

Dr. Grégoire DANOY
Maître assistant
Université de Luxembourg

Dr. Mohammed ALSWAITTI
Chercheur post-doctorant
Université de Luxembourg

Ms. Hedieh HADDAD
Doctorante
Programme de recherche
Université du Luxembourg

Ms. Maria HARTMANN
Doctorante
Programme de recherche
Université du Luxembourg

Mr. Simon MANUEL COMBARRO
Doctorant
Programme de recherche
Université du Luxembourg

SnT

ILNAS

“ World Standards Day 2022 ” OCTOBER 2022

ILNAS-SnT Research Programme and Standardisation Education

Dr. Grégoire Danoy

Research Scientist, Deputy Head PCO Group

University of Luxembourg

UNIVERSITY OF LUXEMBOURG

Parallel Computing and Optimisation Group

http://pcog.uni.lu

Research Topics:
- Parallel/Decentralised computing
- Optimisation/Search/Learning

Aim:
- Efficient, scalable and robust solutions to solve large-scale discrete/combinatorial problems.

Applications:
- Robust/sustainable/efficient HPC/Grid/Cloud/IoT
- Unmanned Autonomous Systems (UAS)
- Next generation networks and protocols
- Systems Bio-medicine
- Information/Document Management for Bio and Finance

Management:
- Head: Prof. Pascal Bouvry
- Deputy Head: Dr. Grégoire Danoy

20+ researchers

1 Professor

4 Research Scientists

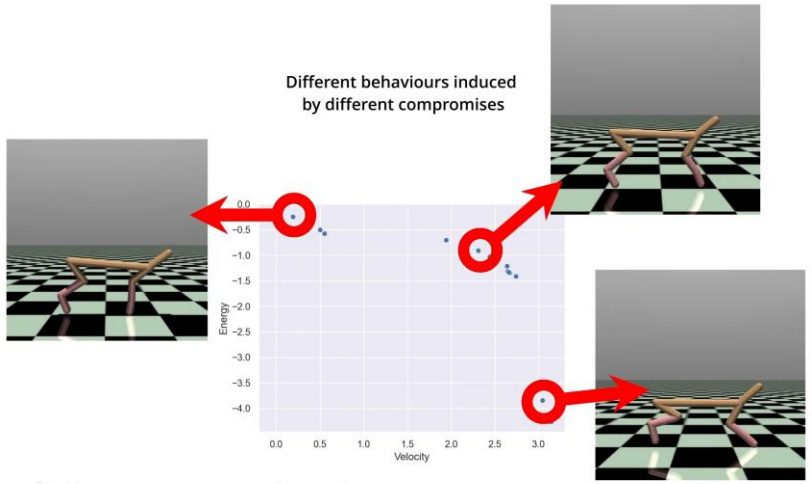
7 Postdocs

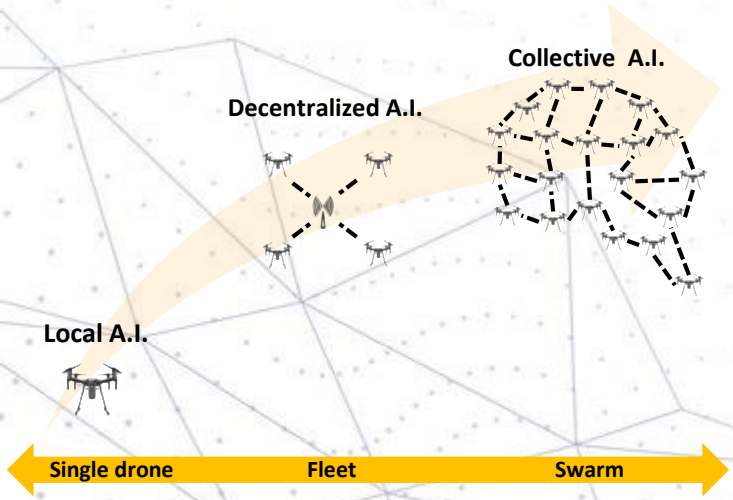
8 PhD students

12 nationalities

Parallel Computing and Optimisation Group

Focus Area: Parallel & Evolutionary Computing, Machine Learning, Swarm Intelligence





Focus Area: High-Performance Computing

ILNAS

Office of Naval Research Global Science & Technology

EUROPEAN DEFENCE AGENCY

Luxembourg National Research Fund

uni.lu | SNT

Research & Education Collaboration

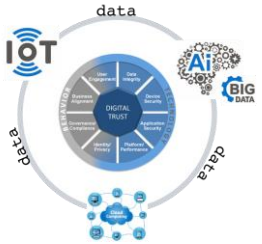
Education Programme
First Smart ICT Certificate

Education Programme
Second Smart ICT Certificate

Research Programme
Second Research Programme

Education Programme
Master in Technopreneurship

2015 2017 2018 2021



Research Programme
First Research Programme

Education Programme

University Certificate “Smart ICT for Business Innovation”

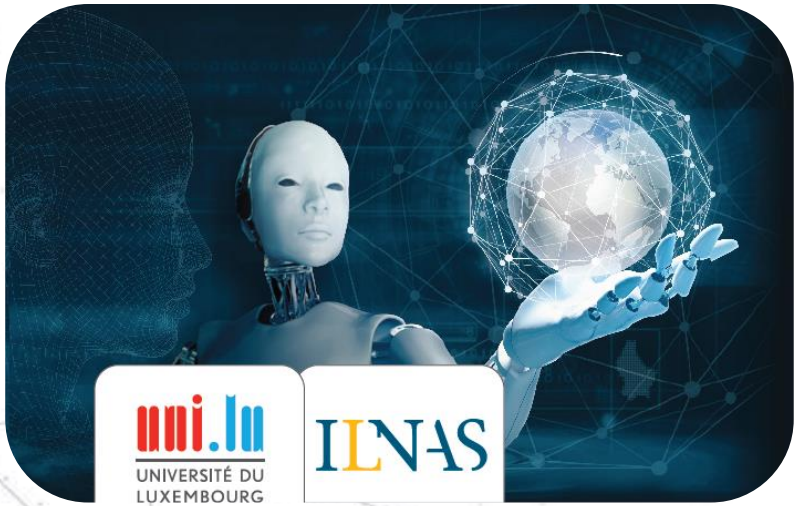
2 promotions

29 students registered

20 students graduated

Master in Technopreneurship

Mastering Smart ICT, Standardisation and Digital Trust for Enabling Next Generation of ICT Solutions



- **First promotion:** February 2021 to February 2023
- **Objective:** **University Master on Smart ICT, technical innovation, technical standardization and digital trust**
  - Will answer national priorities related to "Smart Secure ICT" topics, providing a smart way to link technology, standards and the business world, while creating an additional means of innovation at the national level

Master in Technopreneurship

Mastering Smart ICT, Standardisation and Digital Trust for Enabling Next Generation of ICT Solutions

60 ECTS

2-year lifelong learning

12 students

Blocks and Modules	ECTS
STANDARDISATION	
1. Smart Secure ICT and Innovation	1
2. Technical Standardisation	3
SMART ICT	
3. Smart ICT Technologies I	5
4. Smart ICT Technologies II	5
DIGITAL TRUST FOR SMART ICT	
5. Security for Smart ICT I	2
6. Security for Smart ICT II	3
7. Trust Architectures for Smart ICT	4
TECHNOPRENEURSHIP	
8. Management of Business and Technical Innovation	3
9. Digital Intelligence	2
10. Legal Aspects	2
MASTER THESIS	
12. Master Thesis	30
Total	60

12 modules

327 hours of teaching

Internship (750 hours)

Master in Technopreneurship

http://mtech.uni.lu

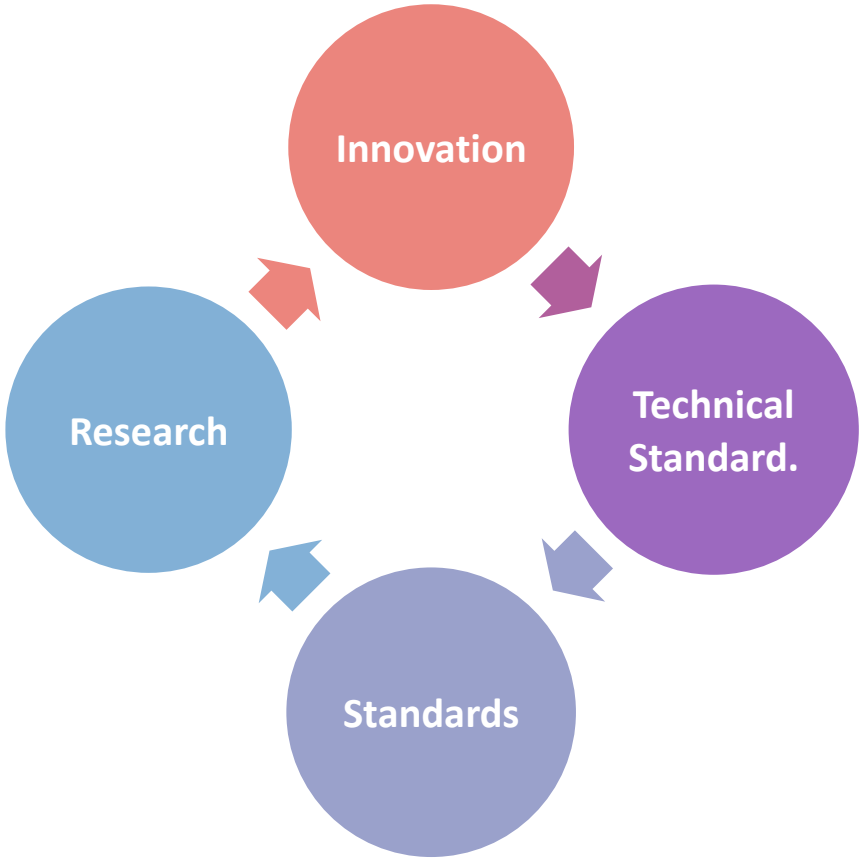
In a glance

DURATION:	4 semesters - including 1 semester internship
CREDITS:	60 ECTS
LANGUAGE:	English
ORGANISATION:	courses organised on Fridays and Saturdays, every two weeks
PLACE:	alternately at the LLLC (Friday) and at the University of Luxembourg (Saturday)
REGISTRATION:	6.400 € for the 4 semesters
APPLICATION PERIOD:	Sep - Dec 2022
START:	February 2023

The First Research Programme

Technical Standardization Research

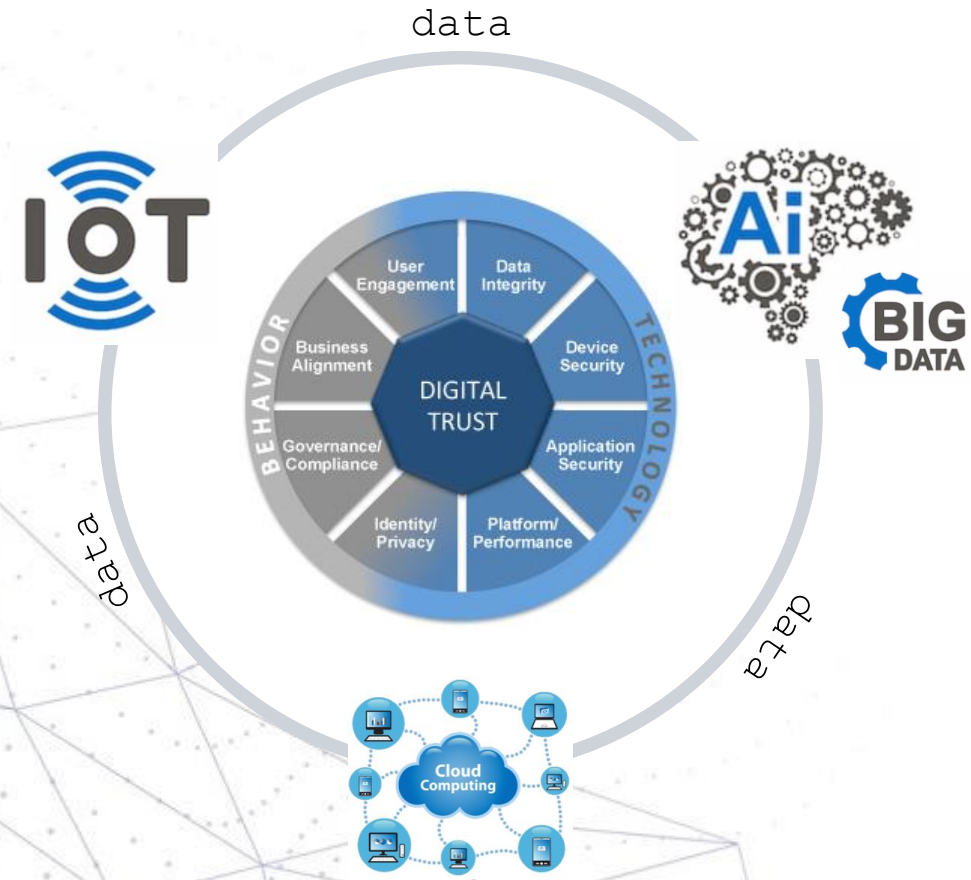
- **Objective**
  - Optimizing the interface and exchange between researchers and technical standardization
- Analyzing **standardization processes**
  - Diffusion, influence, impact
- Aimed **outcomes**
  - Opportunities for researchers (spreading their innovation)
  - Identifying needs for technical standardization (for existing innovations/product/processes)
  - Shorten the gap between research outcome and technical standardization



First Research Programme - The Smart-ICT Ecosystem

“Technical Standardisation for Trusted Use in the Field of Smart ICT”

NATIONAL STANDARDISATION STRATEGY 2010-2020 & POLICY ON ICT



With special focus on

1. Core scientific research areas
2. Technical standardisation needs
   - Identification of gaps between research and standardisation

Objectives

An innovative environment on digital trust for Smart ICT and related standardisation

Key figures

1 White Paper

1 Technical Report

15 Wide Audience Talks

21 Conference Articles

4 Journal Articles

2 Awards

The Second Research Programme

The Second Research Programme 2021-2024

Technical Standardisation for Trustworthy ICT, Aerospace, and Construction

NATIONAL STANDARDISATION STRATEGY 2020-2030

Construction
Devices for Smart Homes and Smart Buildings

Aerospace
Space Commerce, Exploration, and Mining

ICT
Tools, Techniques, and Algorithms to Assess, Analyze, and Incorporate Security and Privacy Aspects of AI Systems

Core research pillars

- ICT
- Aerospace
- Construction

With special focus on

- Core scientific research areas
- Technical standardisation needs
- Identification of gaps between research and standardisation

Objectives

- Deepen data and AI capabilities and continuous drive innovation in the 3 growing sectors of Luxembourg

The Team

Dr. Grégoire Danoy

Research Scientist
PhD supervision

Prof. Pascal Bouvry

Principal Investigator
Project coordination
PhD supervision

Dr. Mohammed Alswaitti

Postdoctoral Researcher
PhD students & Project support

Lena Maria Hartmann
(PhD student)
Supervisor: Dr. Grégoire Danoy
Since 15.02.2022
Aerospace

Manuel Combarro Simón

(PhD student)
Supervisor: Prof. Pascal Bouvry
Since 01.11.2021
ICT

Hedieh Haddad
(PhD student)
Supervisor: Prof. Pascal Bouvry
Since 15.01.2022
Construction

Parallel Computing and Optimisation Group

Contact:

Grégoire Danoy
Research Scientist
Deputy Head of PCOG
gregoire.danoy@uni.lu

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SnT

ILNAS

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Technical Standardisation for Trustworthy ICT, Aerospace, and Construction

Dr. Mohammed Alswaitti
Postdoctoral Researcher
University of Luxembourg

UNIVERSITY OF LUXEMBOURG

The Second Research Programme

ICT

AEROSPACE

CONSTRUCTION

Futuristic Research

Standardizations Spur

Community Awareness

The Second Research Programme 2021-2024

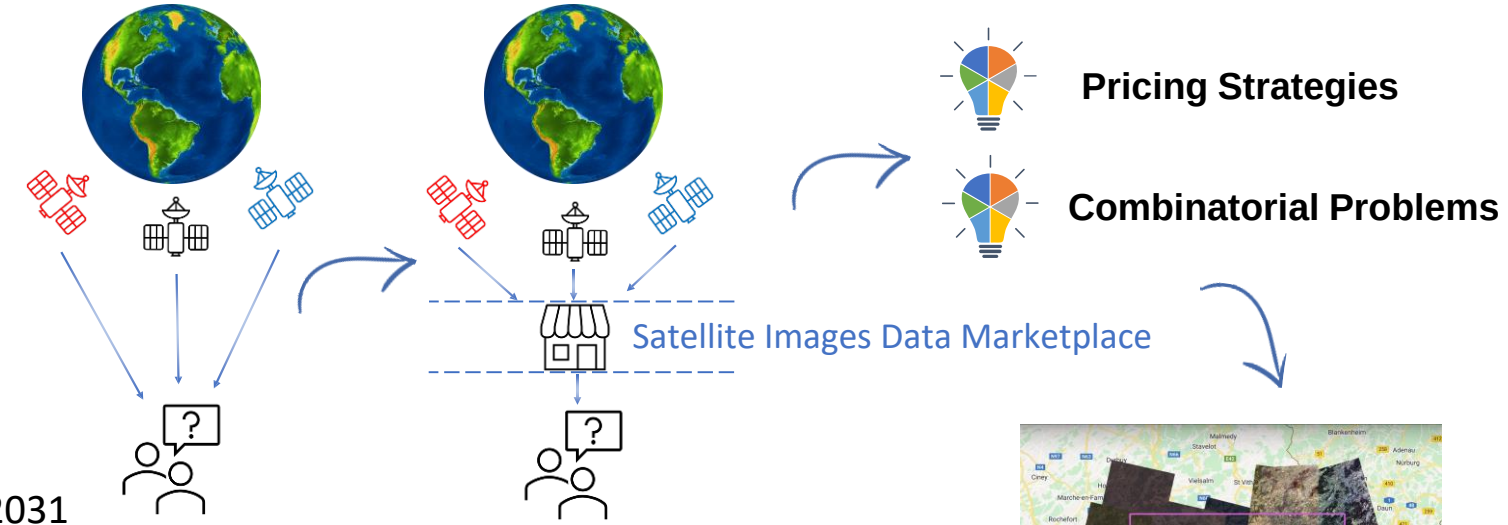
Technical Standardisation for Trustworthy ICT, Aerospace, and Construction

Matching the national technical standardization strategy 2020-2030 with an integrative and synergetic approach in scientific research and technical standardization.

UNIVERSITY OF LUXEMBOURG

ICT

Satellite Images Data Marketplace



Key Figures

13,910 satellites

<500 kg will be launched by 2031

Source Euroconsult, February 2019

8.3% CAGR

(Compound Annual Growth Rate) over 2021-2026

Source Mordor Intelligence, February 2020

€3.38 billion

(Commercial Earth Observation Data Global Sales from Enterprise and Defense, Midstream Segment, in 2022

Source Mordor Intelligence, February 2020

Image mosaicking

Recommendation for Cost Minimization. Increase revenue by demand forecasting

Developing heuristics and Machine learning Algorithms/Tools

Construction

Smart Cities - Building Information Modelling (BIM) & Digital Twin

Digitalised Construction, 2020-2030

Market Size

$18.42 Billion

Source : market research future

CAGR

13.63%

Source : market research future

New Job Creation

700,000 across EU

Traditional Way:

Cost Overruns

Shortage Labor

Human Mistakes in Design

Changing Order

…

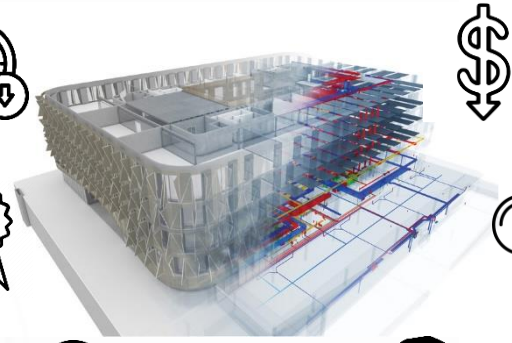
Artificial Intelligence

Machine Learning Tools

Digital Modelling

Optimization Algorithms

Internet of Things



Save Time

Budget Reliability

High rate of quality

Error Detection

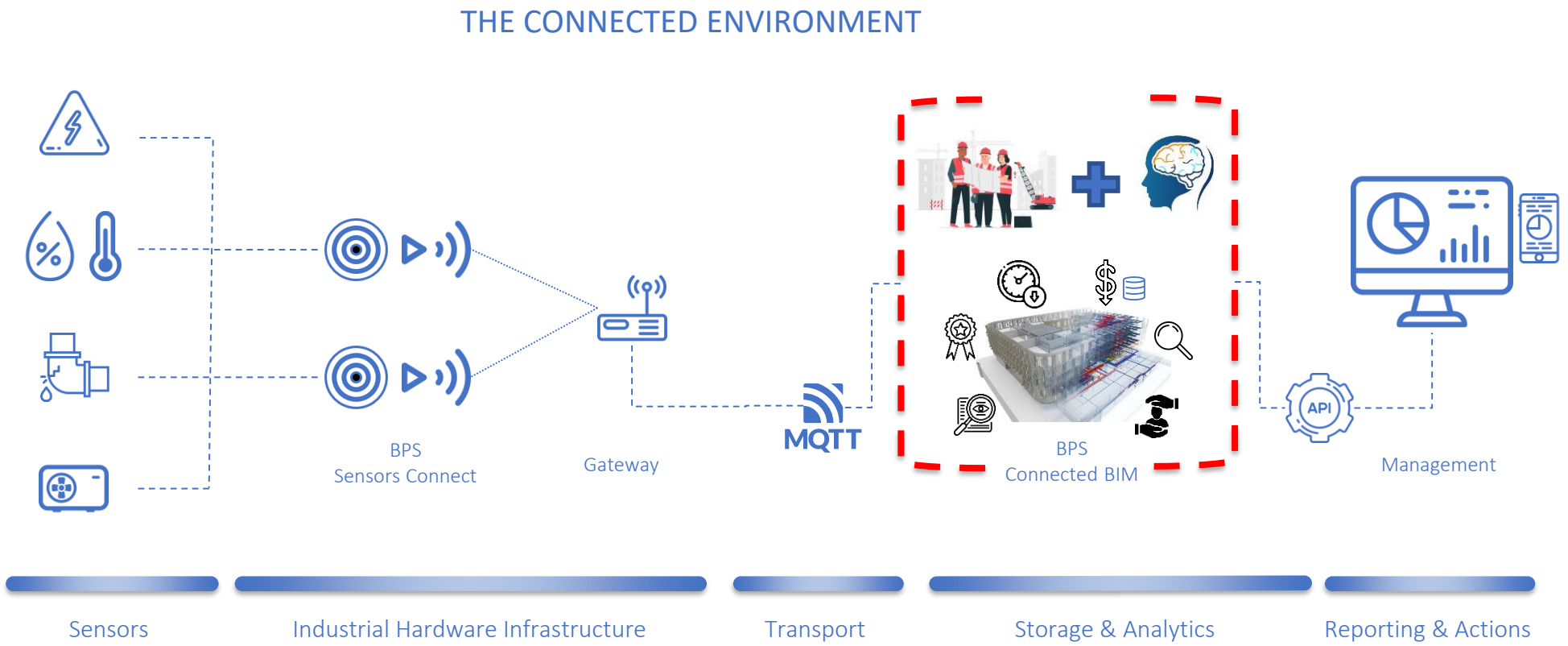
Transparency

Prefabrication

Construction

Smart Cities - Building Information Modelling (BIM) & Digital Twin

Digitalised Construction, 2020-2030



Aerospace

Swarms of Nano-Satellites

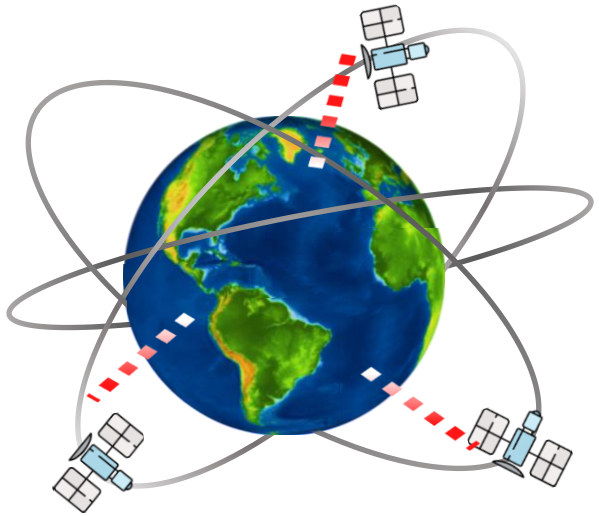
State of the art Challenges

Computation
Power is limited

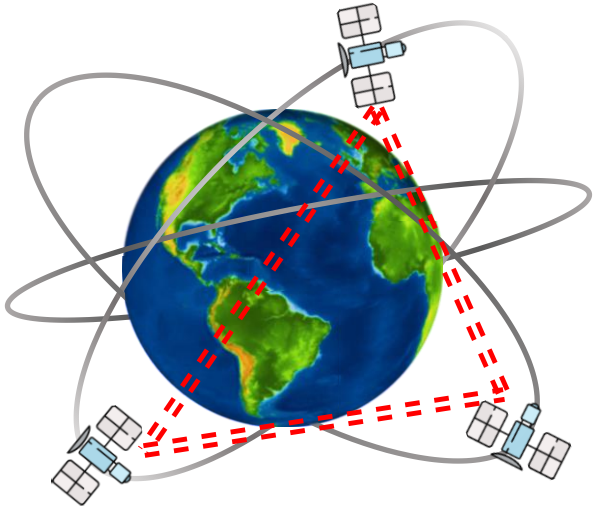
Communication
needs power

Transmission
Latency

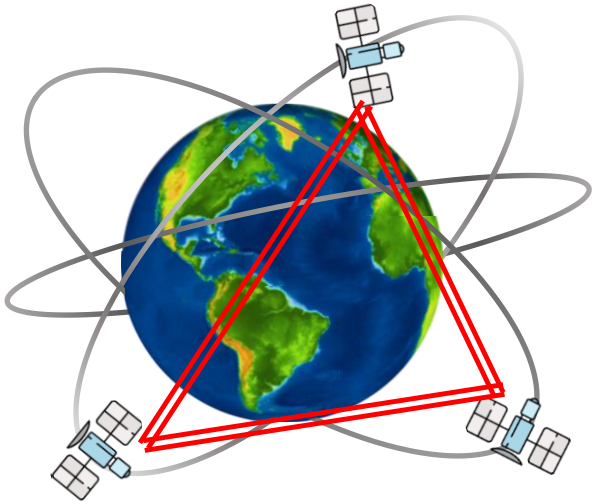
LeSS



Conventional



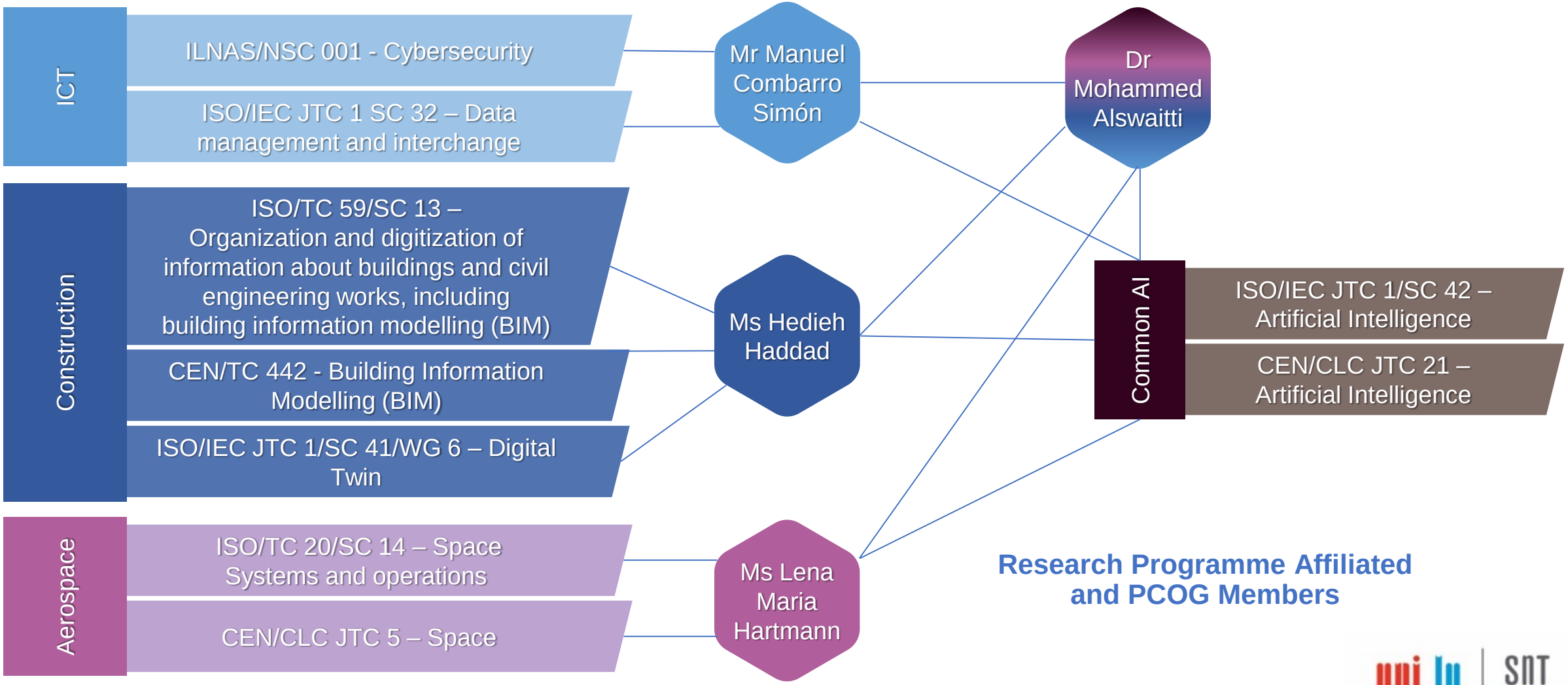
Swarm Data Exchange



Autonomous Onboard Learning

Swarm Model Exchange (Federated Learning)

Involvement in Standardisation Committees, Work Groups, Advisory Groups



Parallel Computing and Optimisation Group

Contact:

Mohammed Alswaitti
Postdoctoral Researcher
Mohammed.alswaitti@uni.lu

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Satellite Images Set Recommendation In A Data Marketplace for Cost Minimization

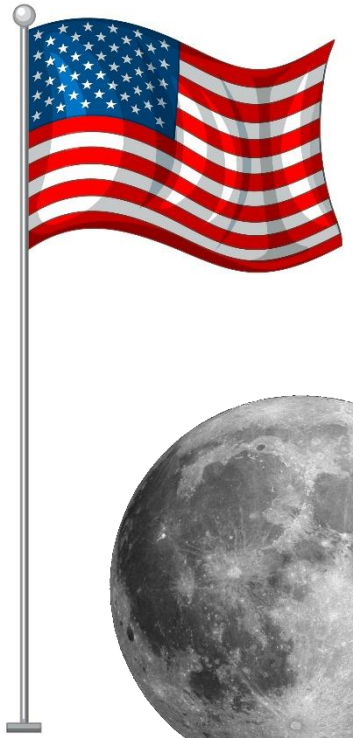
Manuel Combarro Simón

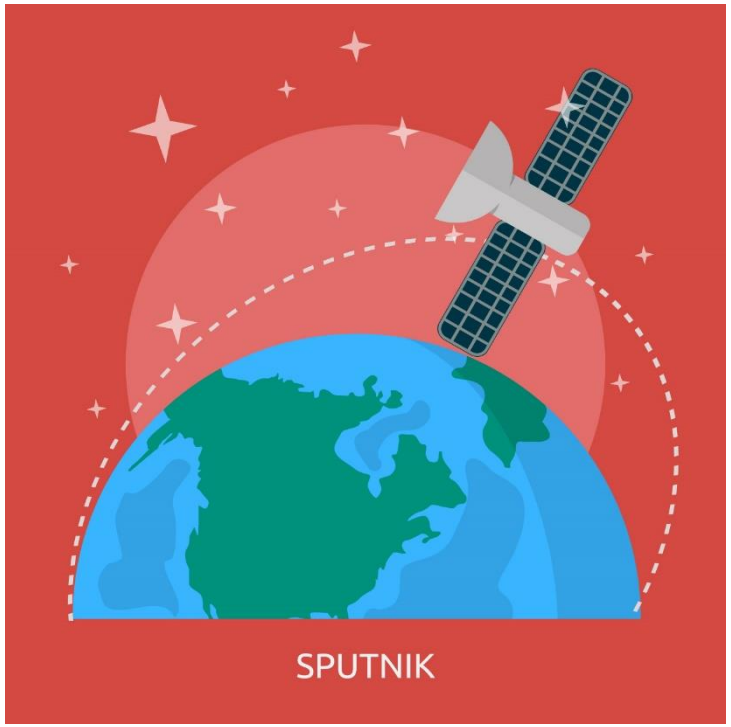
PhD Student (ILNAS/SnT – Aerospace)

University of Luxembourg

UNIVERSITY OF LUXEMBOURG

The space sector is no longer exclusive for governments and military





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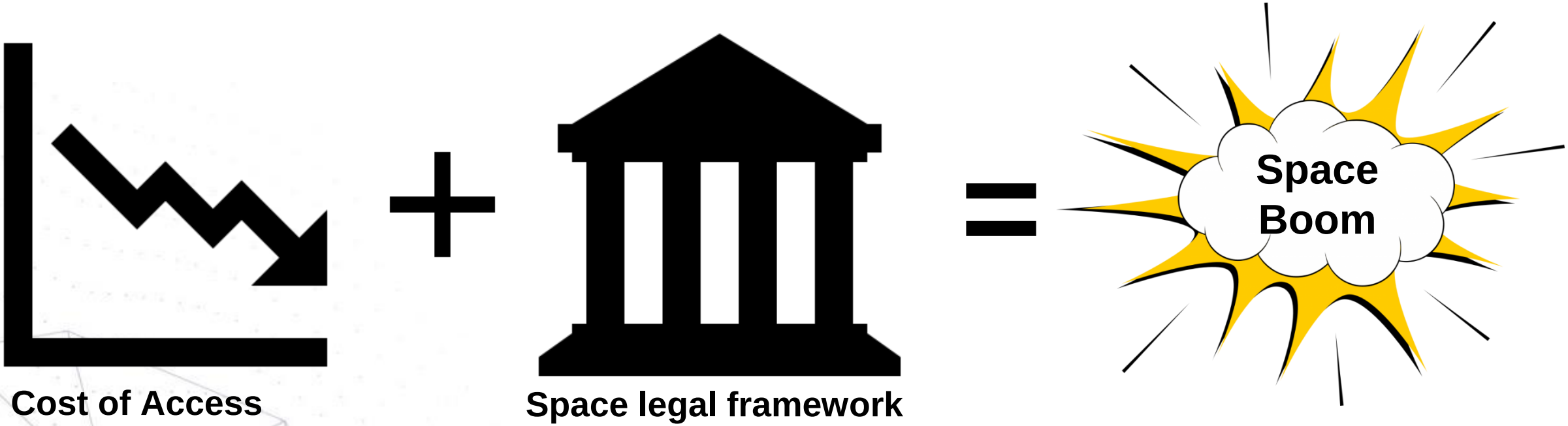
https://www.rawpixel.com/image/7684534/moon-surface-png-sticker-transparent-background
https://www.freepik.com/free-vector/military-aircraft-white-background_27186848.htm#page=2&query=military%20brgfx&position=45&from_view=search&track=sph
https://www.freepik.com/free-vector/satellite-background-design_1026842.htm#query=sputnik%20Graphicastock&position=0&from_view=search&track=sph

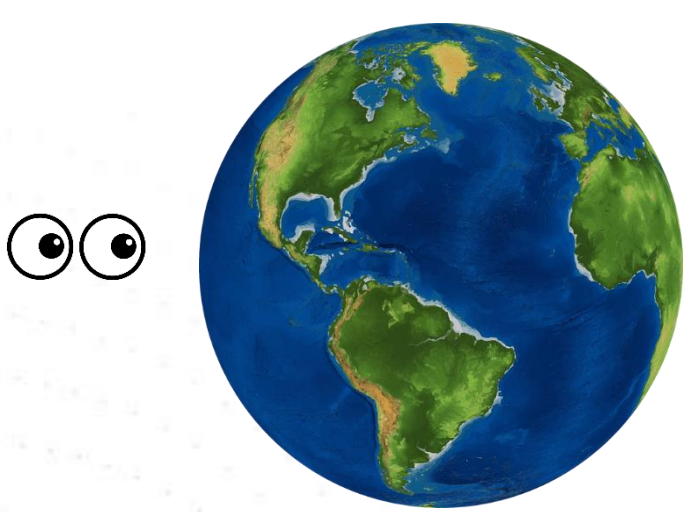
Access to space has become more popular than ever



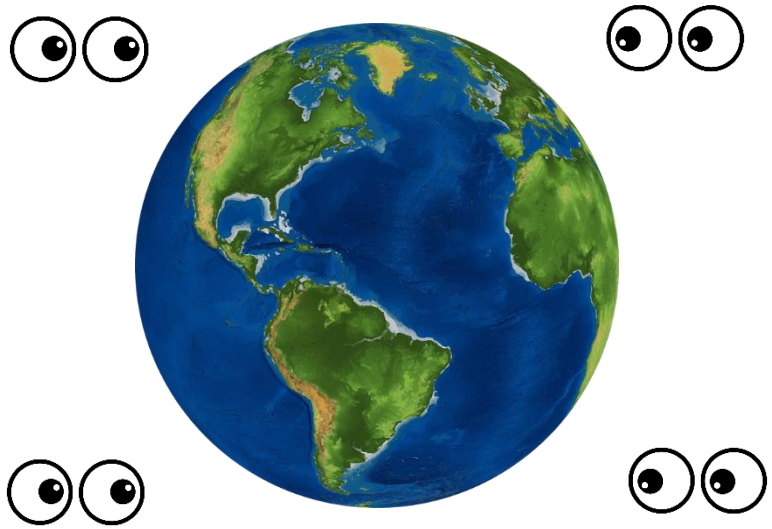
Cost of Access

Space legal framework

Earth Observation



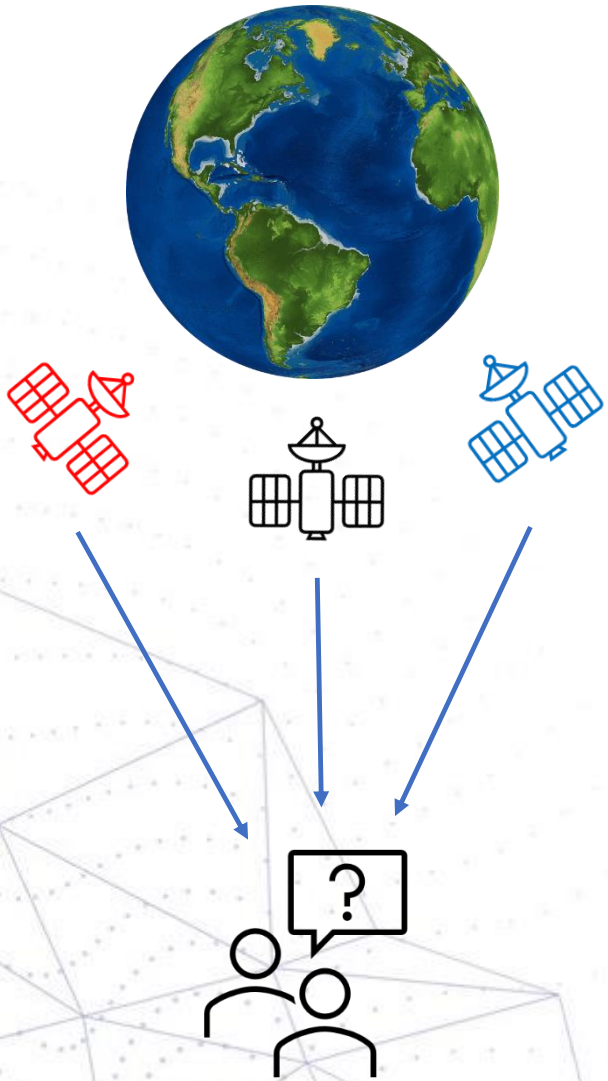
2014
192 EO satellites

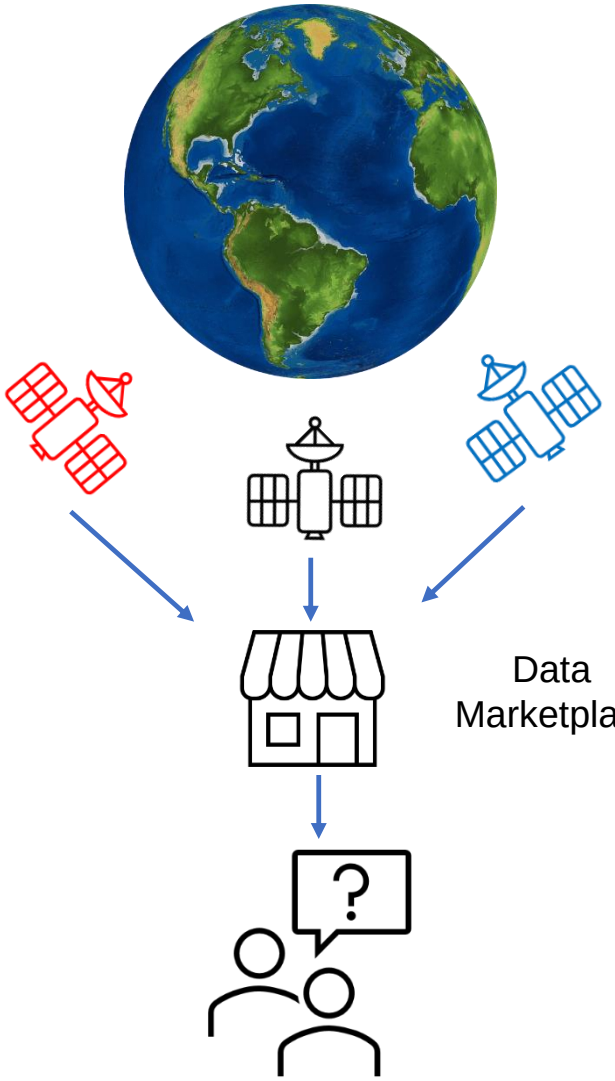


2021
971 EO satellites

>100 TB of satellite imagery per **day**

Satellite Data Marketplace





Data Marketplace ≈ amazon

Satellite Images Price

Two types of data:

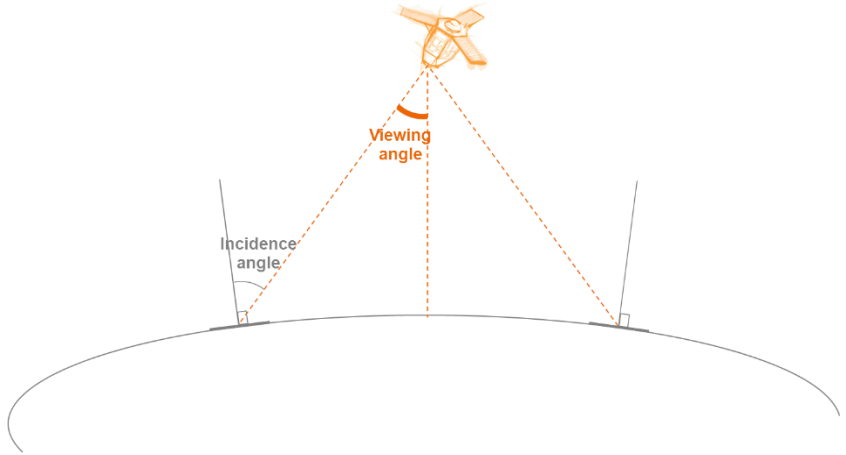
1. Archive
2. Future

Pricing strategies for Archive Data.

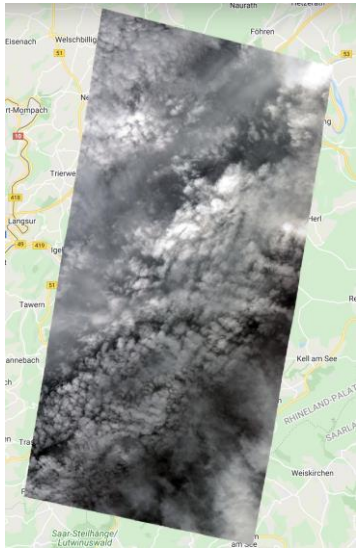
- Resolution (60 m/pixel, 10-30 m/pixel, 0.3-5 m/pixel)
- Provider
- Km^2 fixed for Resolution/Provider
- Cloud coverage
- Incident angle
- Freshness

NOTE: Price per km^2 of the image can range from €2 to €30.

Luxembourg 2586 km^2 => €5172 to €77580



100%



34%

https://www.intelligence-airbusds.com/en/8719-angle-conversion#:~:text=The%20incidence%20angle%20is%20the,the%20pitch%20and%20roll%20angles

Combinatorial Problem

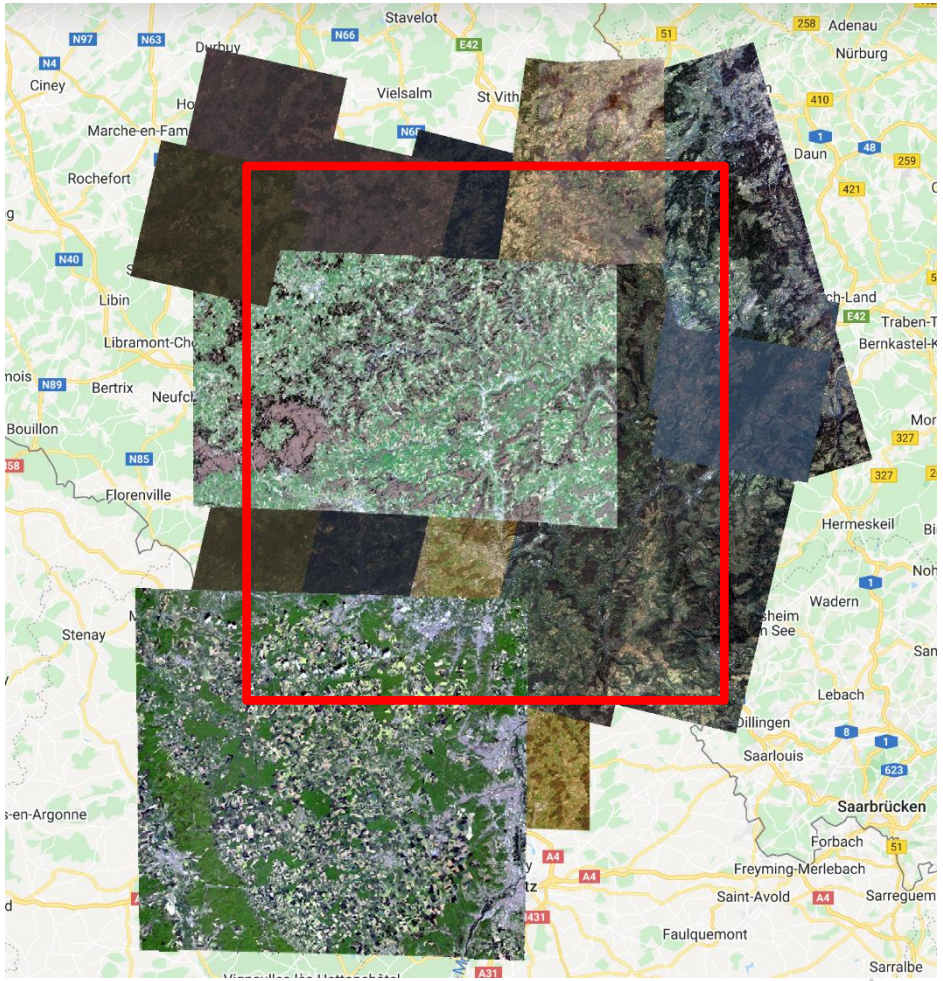
- Combine images to get a final image (mosaic) of a bigger area.
- Each image has a cost depending on provider, resolution, etc
- **Objective**: Minimize total price

Marketplace **Apollo Mapping**

- Cover Luxembourg (6700 km^2)
- 01/01/2022 – 07/06/2022
- Resolution: < 2 m
- Cloud Cover: < 50%
- Incident angle: < 45
- Query results:
  - 174 images
  - 32 selected

NP- Hard

- **Possible combinations**
  - **~2^{174} ➡ ~10^{27} years**

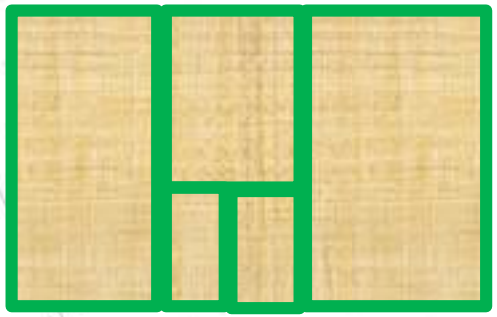


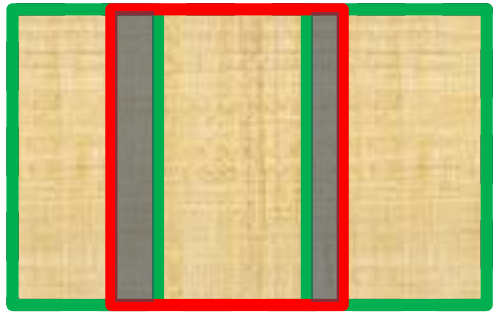
Satellite Image Mosaic Combination Multi-Objective

Objectives

- **Minimize total cost**
  - Minimize number of images (merge is easier)
  - Minimize cloud covering

Cost VS **Min number of images**



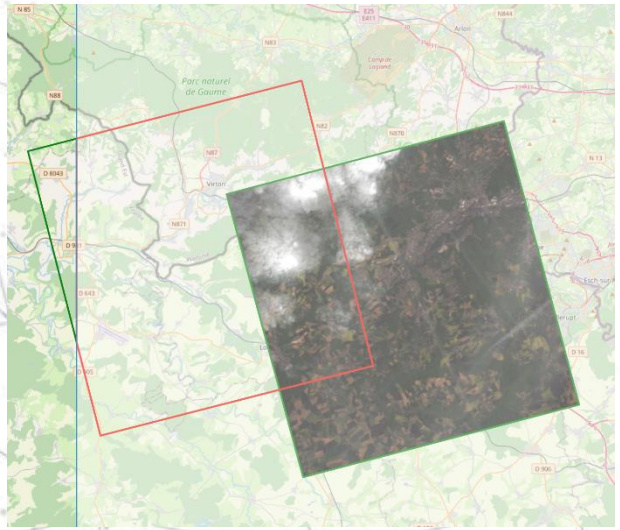


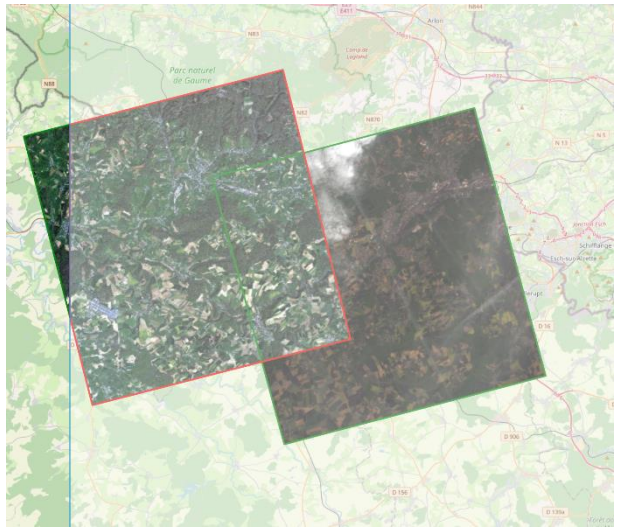
Images (5)	>	Images (3)
Area (€/km^2)	<	Area + overlap (€/km^2)

Satellite Image Mosaic Combination Multi-Objective

Cost  **Cloud coverage %**

The entire image is not covered by clouds. If there is going to be an overlap is better to **overlap cloudy regions and get a cheaper final mosaic with less cloud coverage**





Impact on Standardisation

Gaps between research and standardisation in the satellite images mosaic problem

- Common metadata and format for different providers satellite image providers.
- Minimum requirements of the images to form a mosaic based on the application.

Involvement in Standardisation Committees, Work Groups, Advisory Groups

- **ISO/IEC JTC 1/SC 32** – Data Management
- **ISO/IEC JTC 1/SC 42** – Artificial Intelligence
- **CEN-CENELEC JTC 21** – Artificial Intelligence
- **ILNAS/NSC 001** – Cybersecurity

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Contact:

Manuel Combarro Simón
PhD Student
manuel.combarrosimon@uni.lu

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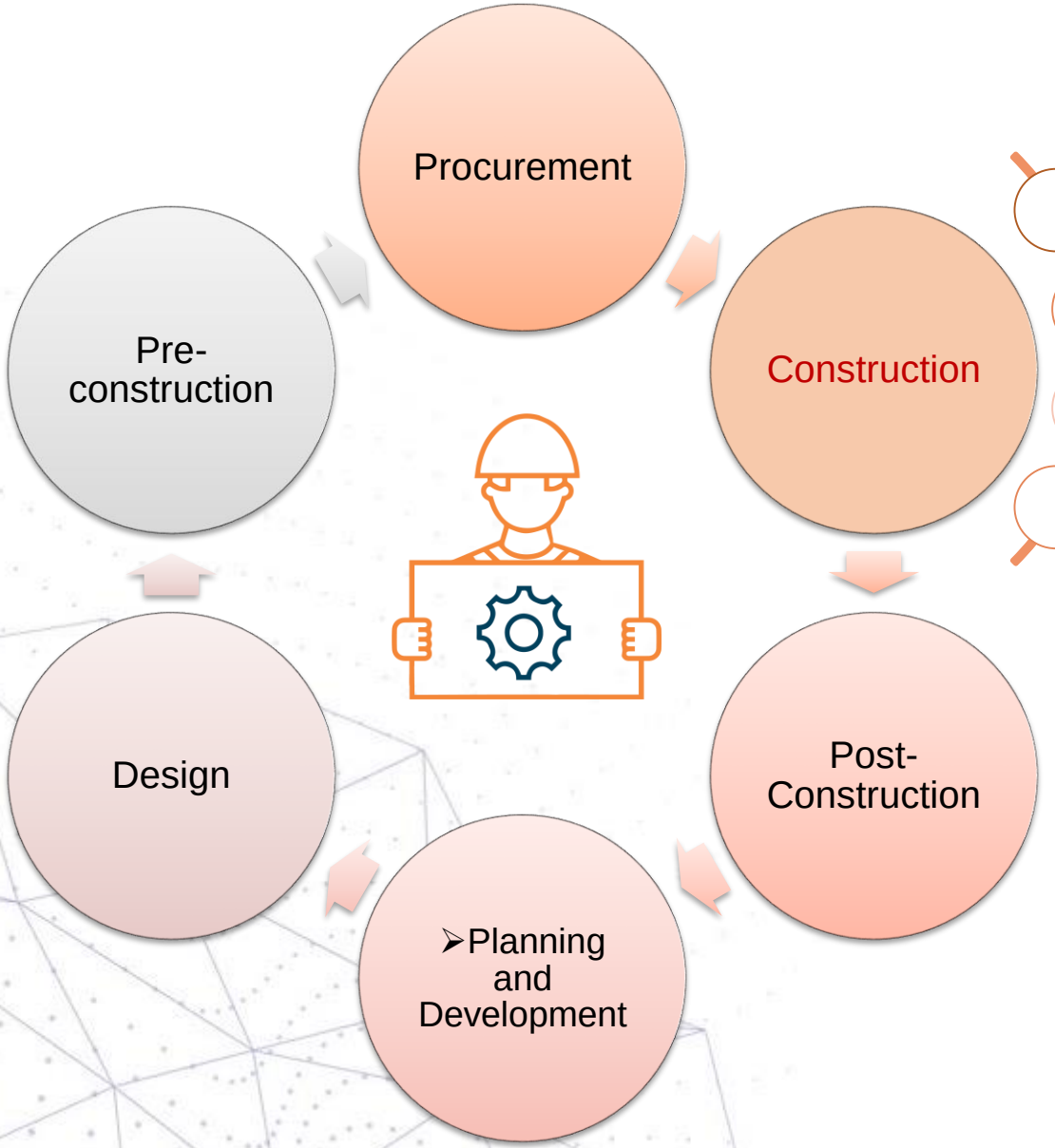
Advanced Building Information Modelling (BIM)

Hedieh Haddad
PhD Student (ILNAS/SnT – Construction)
University of Luxembourg

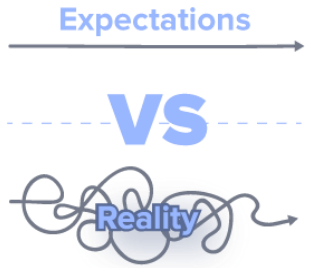
Construction Project Management



- •Ideation and Research
- Define and Plan the Project
- Determine Roles
- Finalize and Execute Construction Plans

Construction Project Management

Time Management



Unrealistic expectations

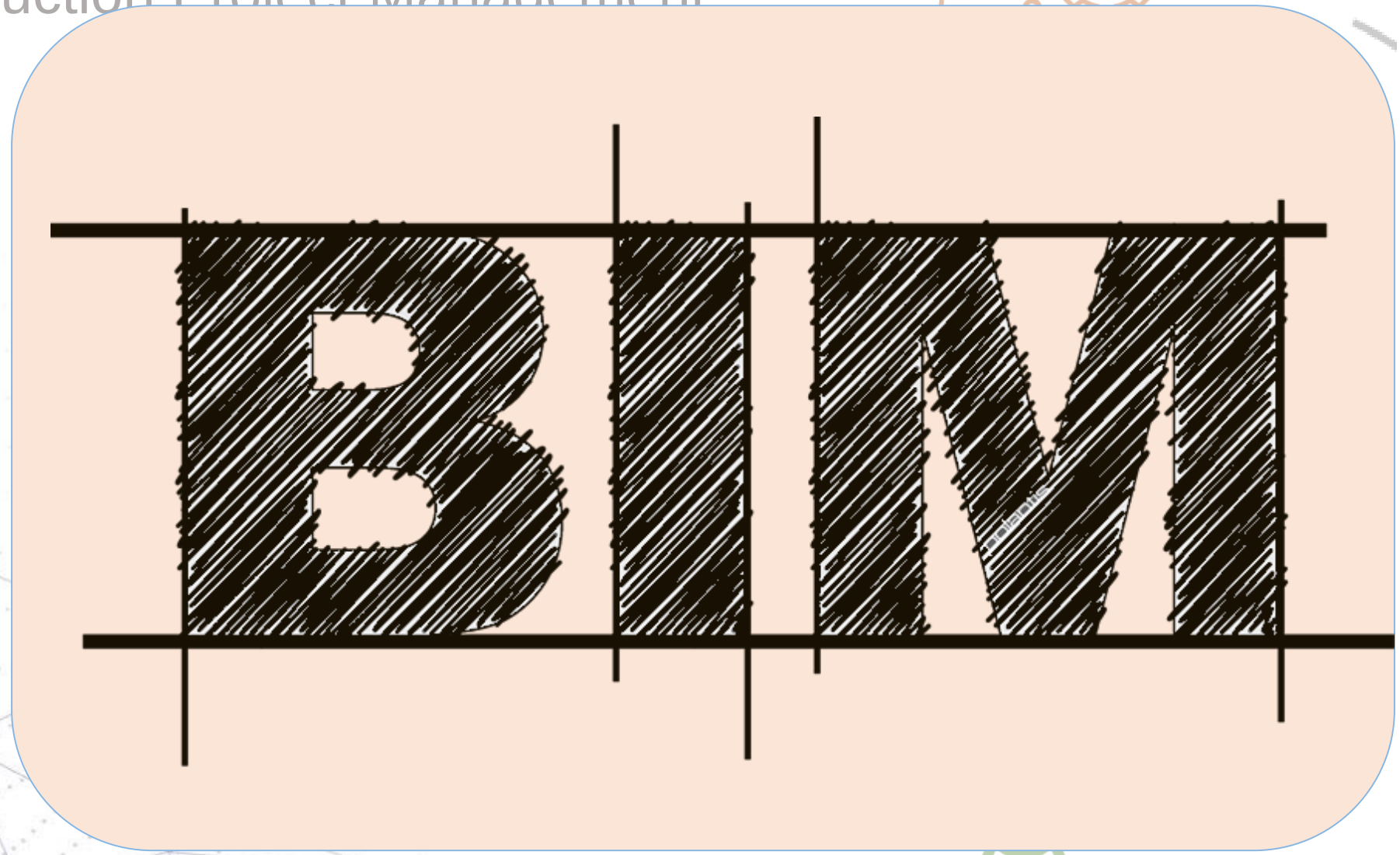
Budget Management

Quality Assurance

Poor Communication and Coordination

Source: gamma-ar

Construction Project Management



Expectations

VS

Reality

Unrealistic expectations

Budget Management

Quality Assurance

Building Information Modelling

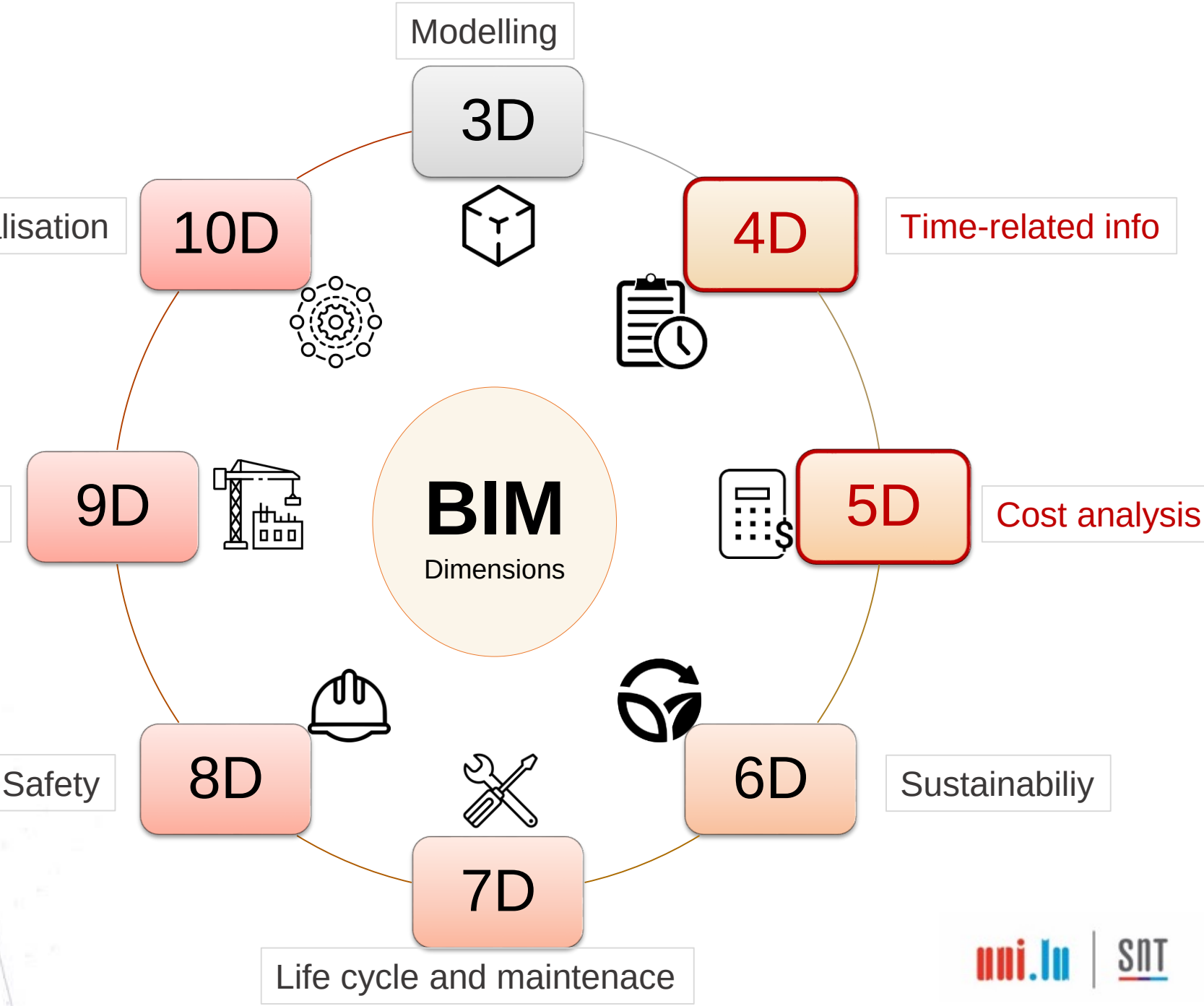
ISO 19650-1:2018 defines BIM as:

“Use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions.”

“How the lifetime of a building has changed?“

Source: British Standards Institution (2019) BS EN ISO 19650: Organisation and digitisation of information about buildings and civil engineering works, including building information modelling - Information management using building information modelling, London: BSI

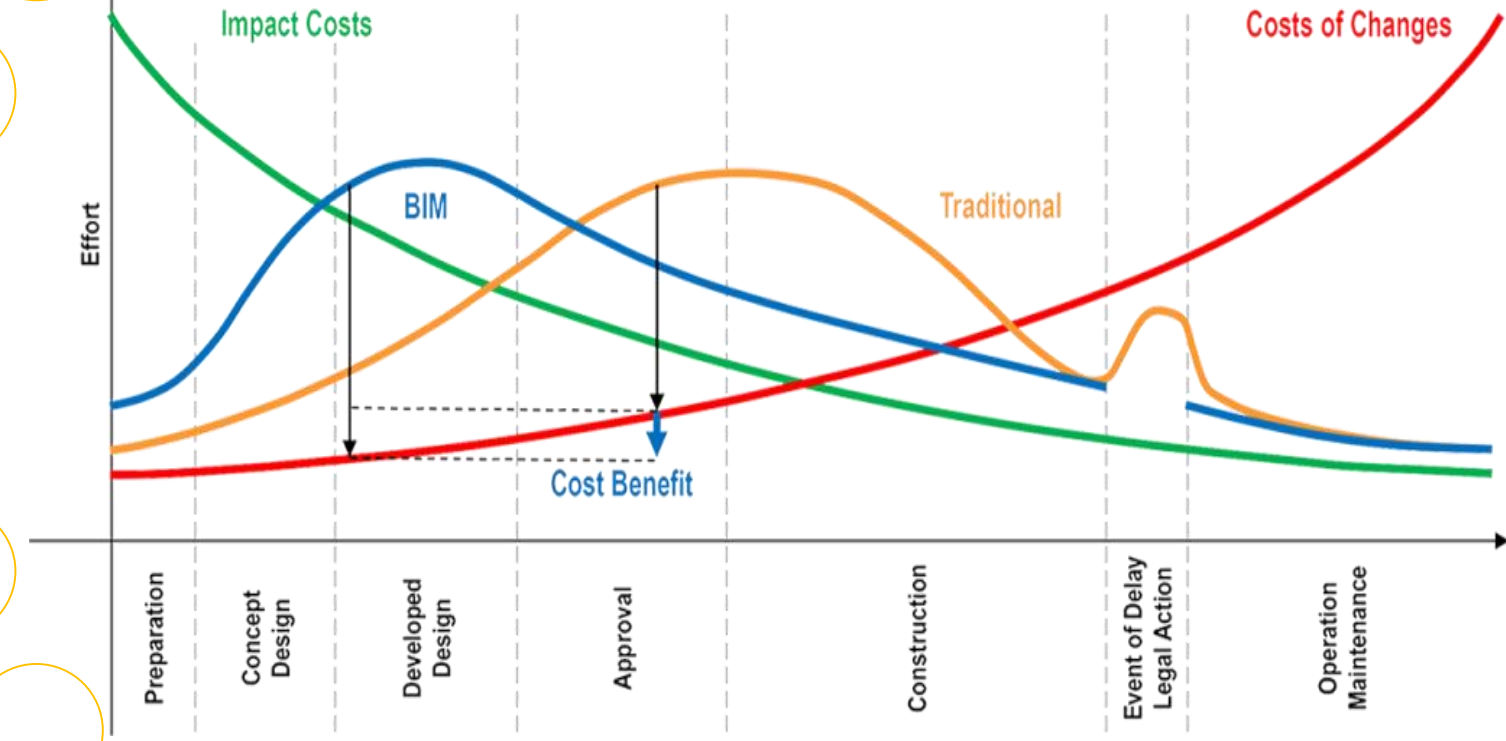
Dimensions of BIM



Source: ACCA SOFTWARE

•How BIM can affect the time and costs?

- ➢improve integration of design phase and construction phase
- increase collaboration between construction sections
- decrease design error
- reduce clash detection
- improve recycling
- boost integration of cost and time



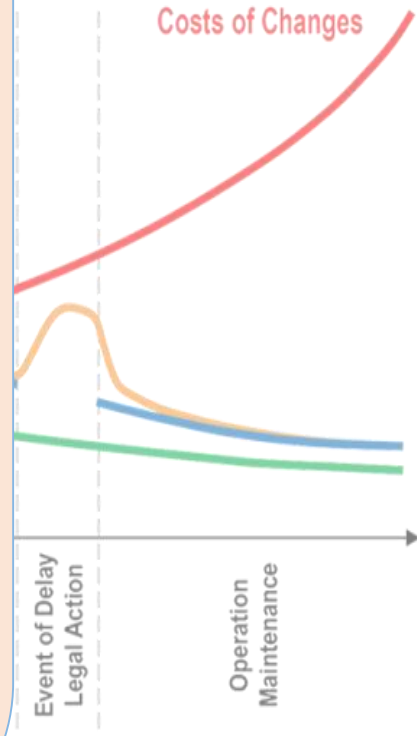
Source: The MacLeamy Curve (2004)

- How BIM can affect the time and costs?

➢improve integra

increase collaborati

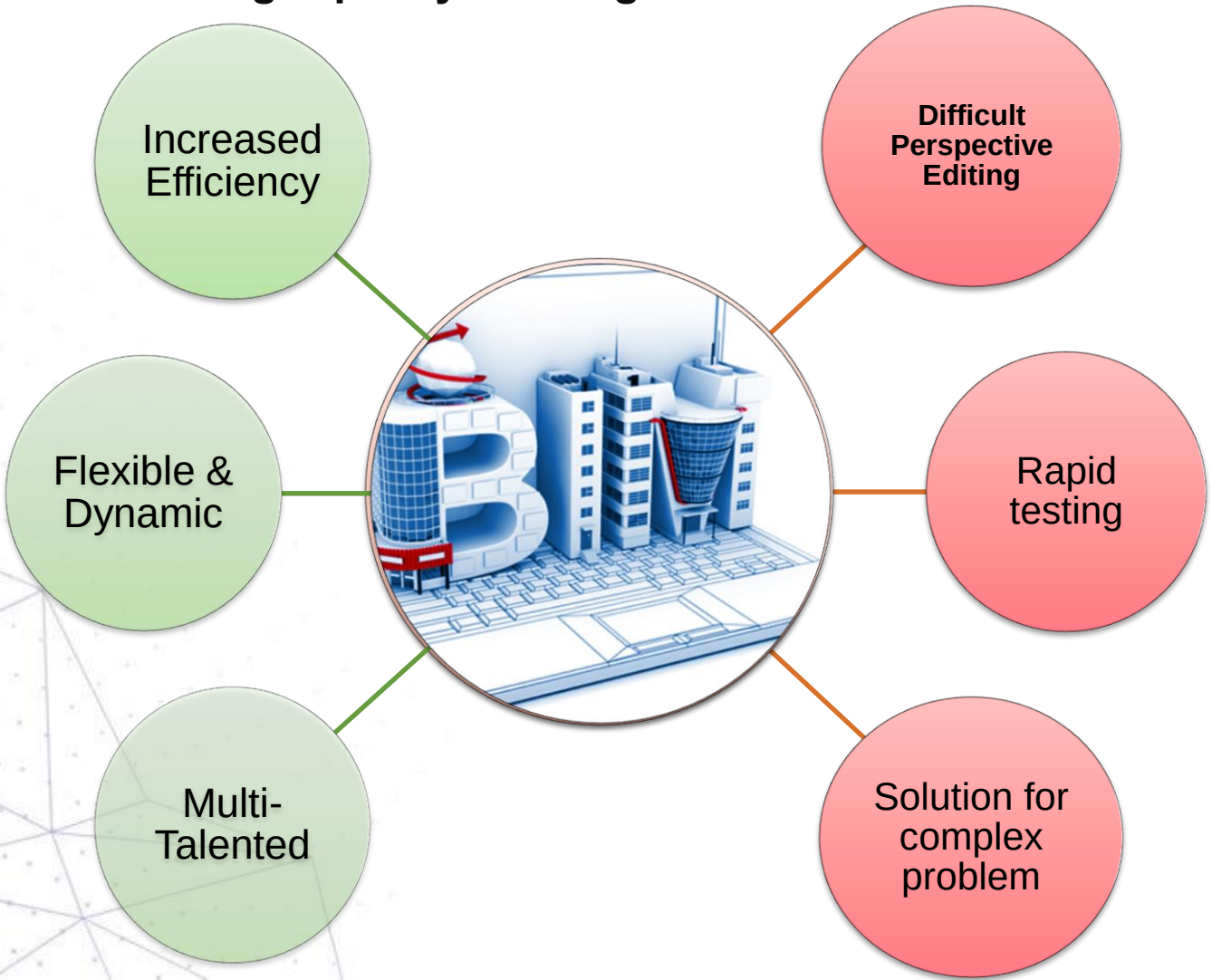
How can BIM be implemented?
What is the role of AI?



•Revit:

AUTODESK REVIT

“Revit® BIM software for create high-quality buildings and infrastructure models.”



Source:Autodesk

Dynamo:

Dynamo

- *is a visual programming tool that is intuitive to the Revit environment.*
- *creates an algorithm to read, analyse, and edit data*
- *Can be including Indirect prices regarding additional time for process.*
- *With Dynamo, complicated programming scripts can be applied into 3D model.*

Source: Autodesk

Reinforcement Learning can overcome challenges we faced.

- ➢ *This problem can be identified as multi-objective problem with more than one objective to optimized.*
- The states of a construction project are unique.
- *IT's a Dynamic Programming so Markove Decision Process (MDP) is needed.*
- *Some ML algorithms like RL is built on top of MDP.*

•Research Workflow

Making a building model

- **Using Revit**
- **this could be applied to a real building:**
  - **under construction**
  - **existing construction**

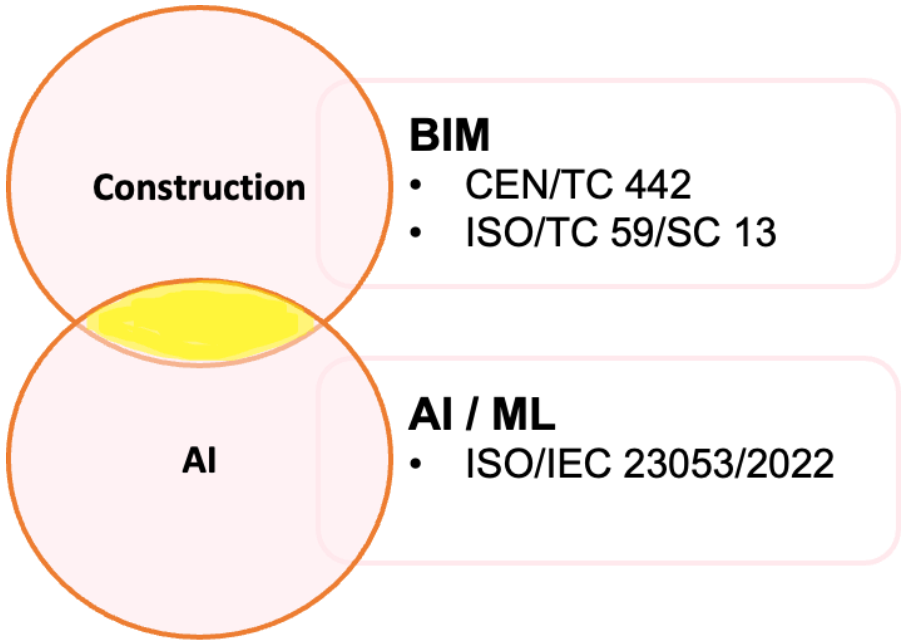
adding the programming interface

- Using Dynamo
- To customize building information modelling

applying optimization algorithms

- Using Reinforcement Learning
- To make some recommendations about the required budget and time

Impact on Standardisation



Involvement in Standardisation Committees, Work Groups, Advisory Groups:

- **ISO/TC 59/SC 13** - Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)
- **CEN/TC 442** - Building Information Modelling (BIM)
- **ISO/IEC JTC 1/SC 41/WG 6** – Digital Twin
- **ISO/IEC JTC 1/SC 42** – Artificial Intelligence
- **CEN-CENELEC JTC 21** – Artificial Intelligence

"Of the more than 21700 International Standards and related documents, ISO has over 1100 related to buildings and construction."*

To be continued …

Parallel Computing and Optimisation Group

Contact:

Hedieh Haddad
PhD Student
Hedieh.haddad@uni.lu

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@SnT_uni_lu

SnT, Interdisciplinary Centre for Security, Reliability and Trust

“ World Standards Day 2022 ” OCTOBER 2022

Swarms of Nano-Satellites

Maria Hartmann

PhD Student (ILNAS/SnT – Aerospace)

University of Luxembourg

Autonomous satellite swarms are the future

“How swarms of small satellites could revolutionize space exploration” [1]

October 4, 2016

“NASA Works to Give Satellite Swarms a Hive Mind” [2]

Sep 1, 2021

“An **unmanned aerial vehicle** (UAV) **swarm** can be simply defined as a group aerial robotic platform, usually similar in form, coordinating and cooperating to achieve a common goal. Swarms extend robotic capabilities beyond those of a single vehicle through various methods of coordination and cooperation between the different agents.“ [3]

Source: Eutelsat

[1] How swarms of small satellites could revolutionize space exploration | Stanford University School of Engineering
[2] Giving Satellite Swarms a Hive Mind | NASA
[3] Loianno, G., Weinstein, A., Kumar, V. (2020). Unmanned Aerial Vehicles Swarms. In: Ang, M., Khatib, O., Siciliano, B. (eds) Encyclopedia of Robotics. Springer, Berlin, Heidelberg.

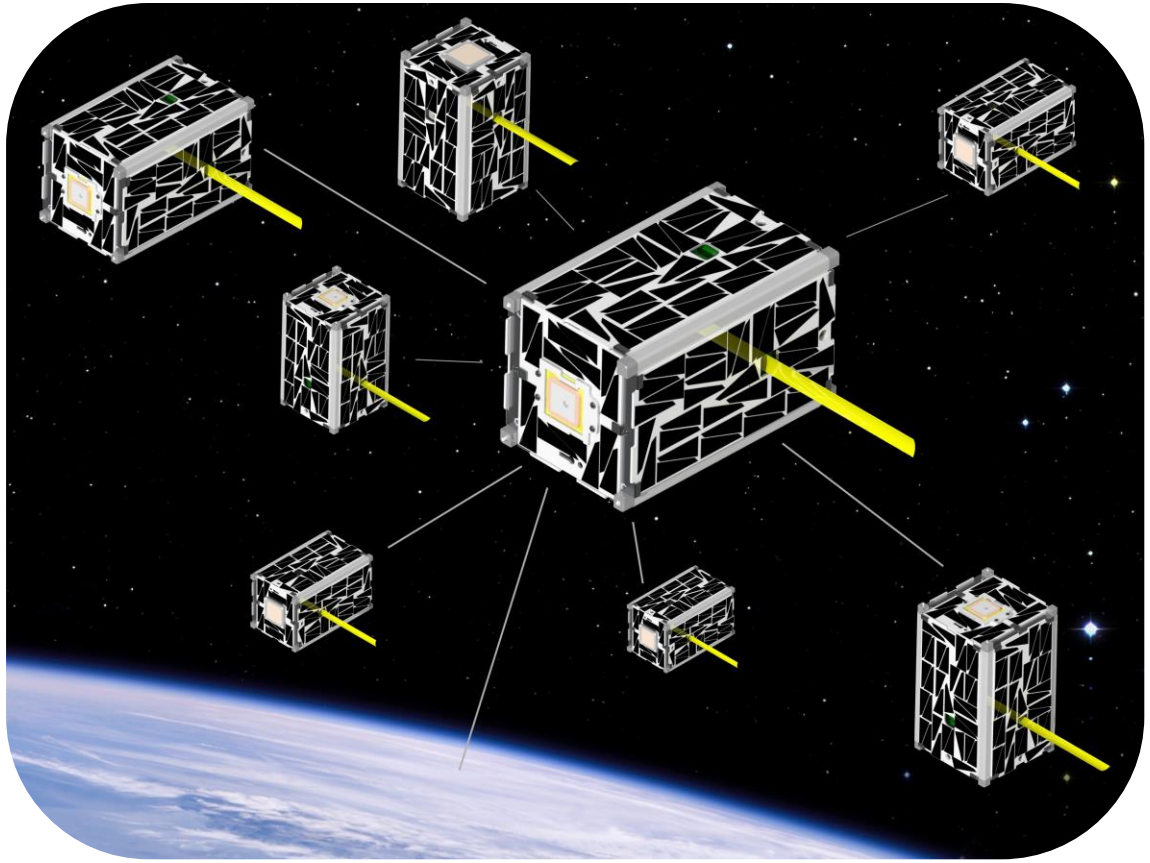
Autonomous satellite swarms have systemic advantages

Flexibility:
- Can manifest collective behaviour beyond individual capability
- Can react to unforeseen circumstances without delay

Scalability:
- Number of satellites may be extended over time

Resilience:
- Can compensate for loss of individual satellites

Cost-effectiveness:
- Can mass-produce standard multi-purpose satellites
- Launching smaller satellites is less expensive



Source: NASA

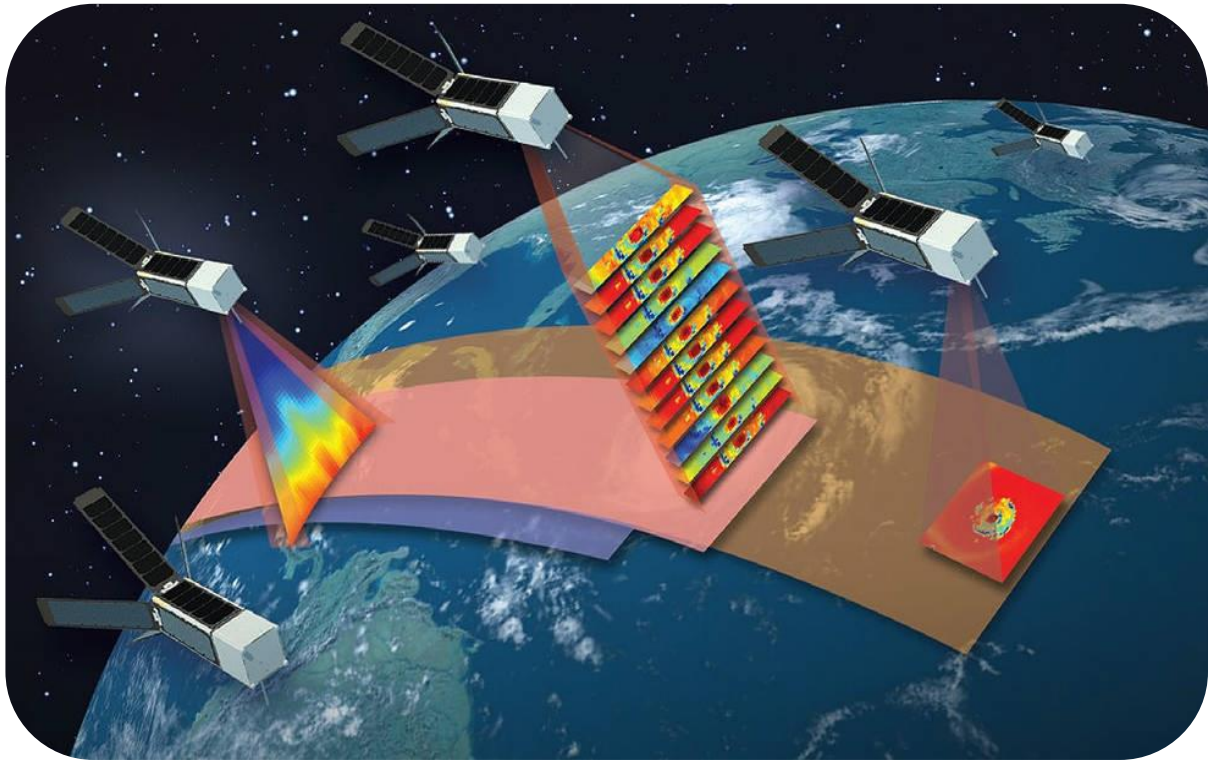
Autonomous satellite swarms have many use cases

Earth observation:
- Fast response times for disaster management
- Multi-view imaging capability

Communication:
- Relay networks for planetary exploration missions

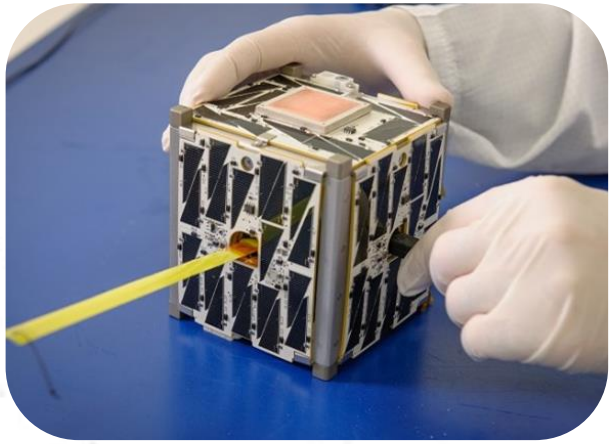
Exploration:
- Deep-space exploration missions
- Heterogeneous swarms for planetary exploration

Mining:
- Support satellite network for mapping, coordination of asteroid mining



Source: NASA/MIT Lincoln Laboratory

Autonomous satellite swarms: state of the art



Source: NASA Ames

CubeSats as readily available, low-cost building blocks

- Modular units of 10x10cm

Source: Technion

Non-autonomous multi-satellite missions in Earth orbit

- GPS, SWARM, TROPICS, ...

Technology demonstration missions for swarm mobility

- SAMSON, EDSN, Starling-1, …

Autonomous satellite swarms face challenges

Constraints on computational power
- Nano-satellites' on-board computers have limited capability

Constraints on communication
- Communication requires power, bandwidth and is susceptible to noise

Long Earth-Satellite transmission latency
- Transmission time is proportional to distance

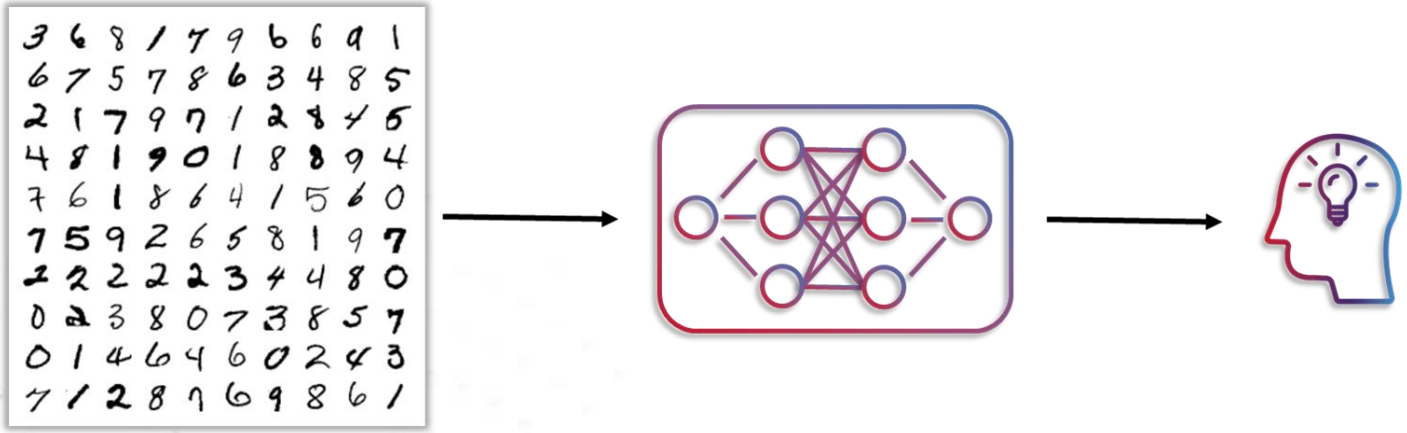
Federated Learning can overcome challenges

Constraints on computational power
- Computational load is shared between satellites

Constraints on communication
- Satellites transmit less data

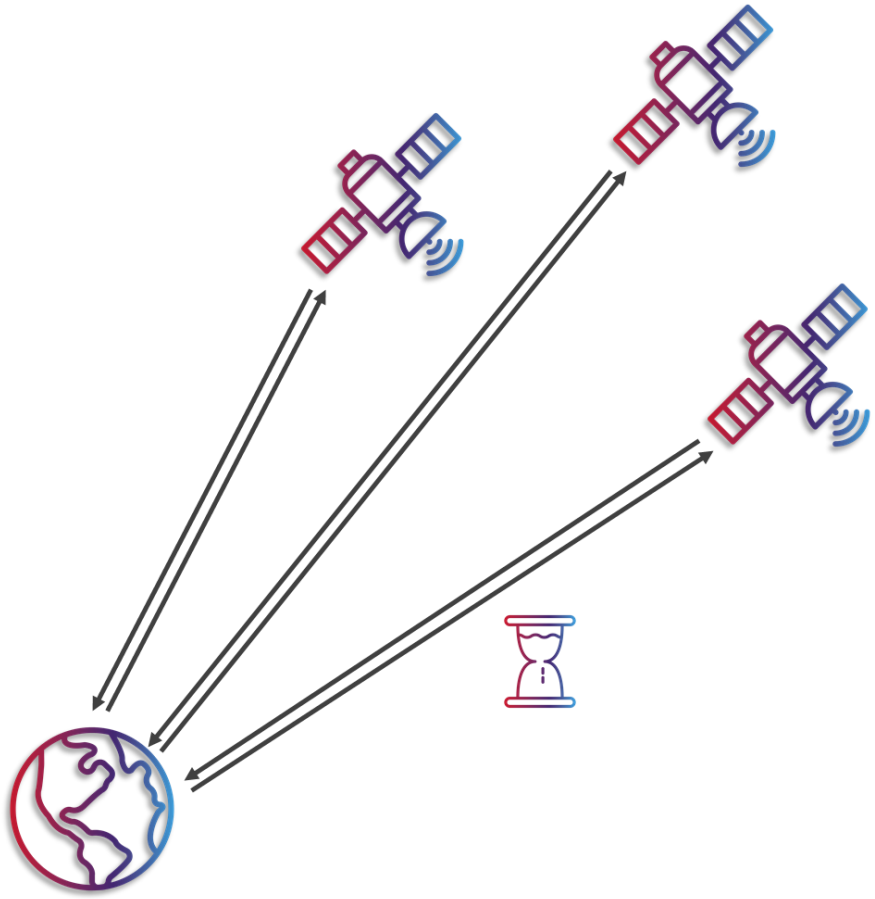
Long Earth-Satellite transmission latency
- Learning is not dependent on a connection to earth

How would classical machine learning work?



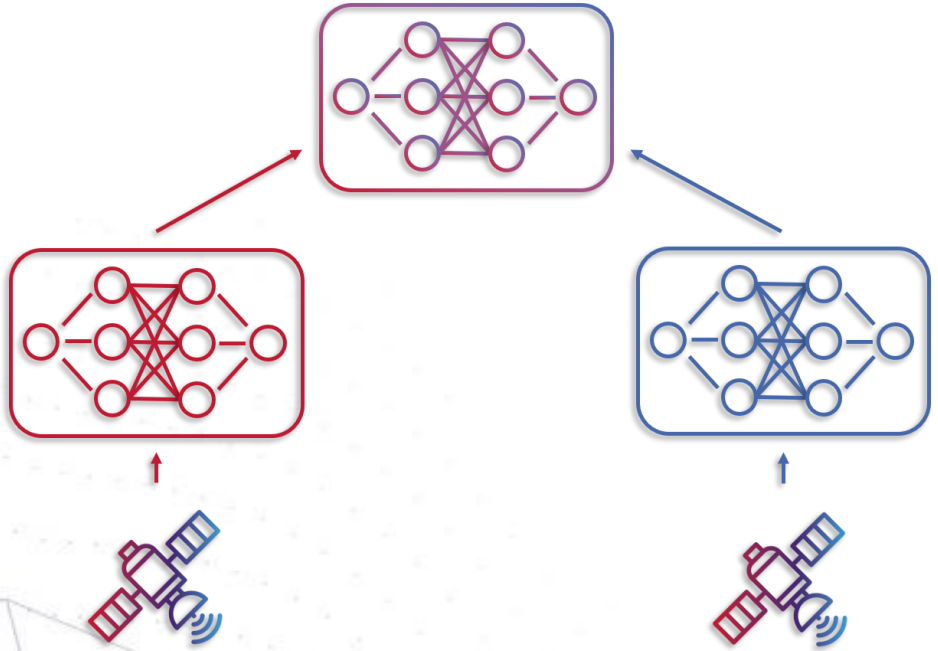
Source: Anatomies of Intelligence

One dataset – one model

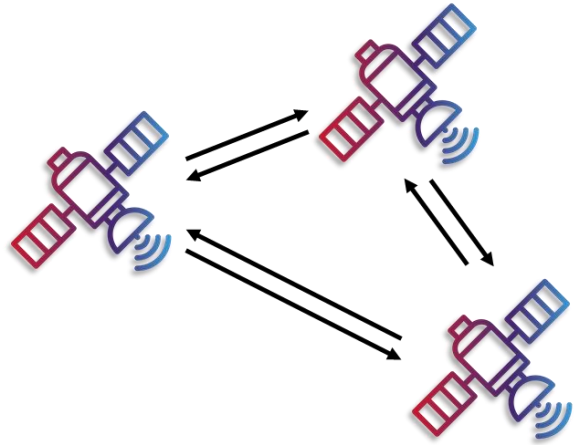


Data aggregation via Earth

How does Federated Learning work?



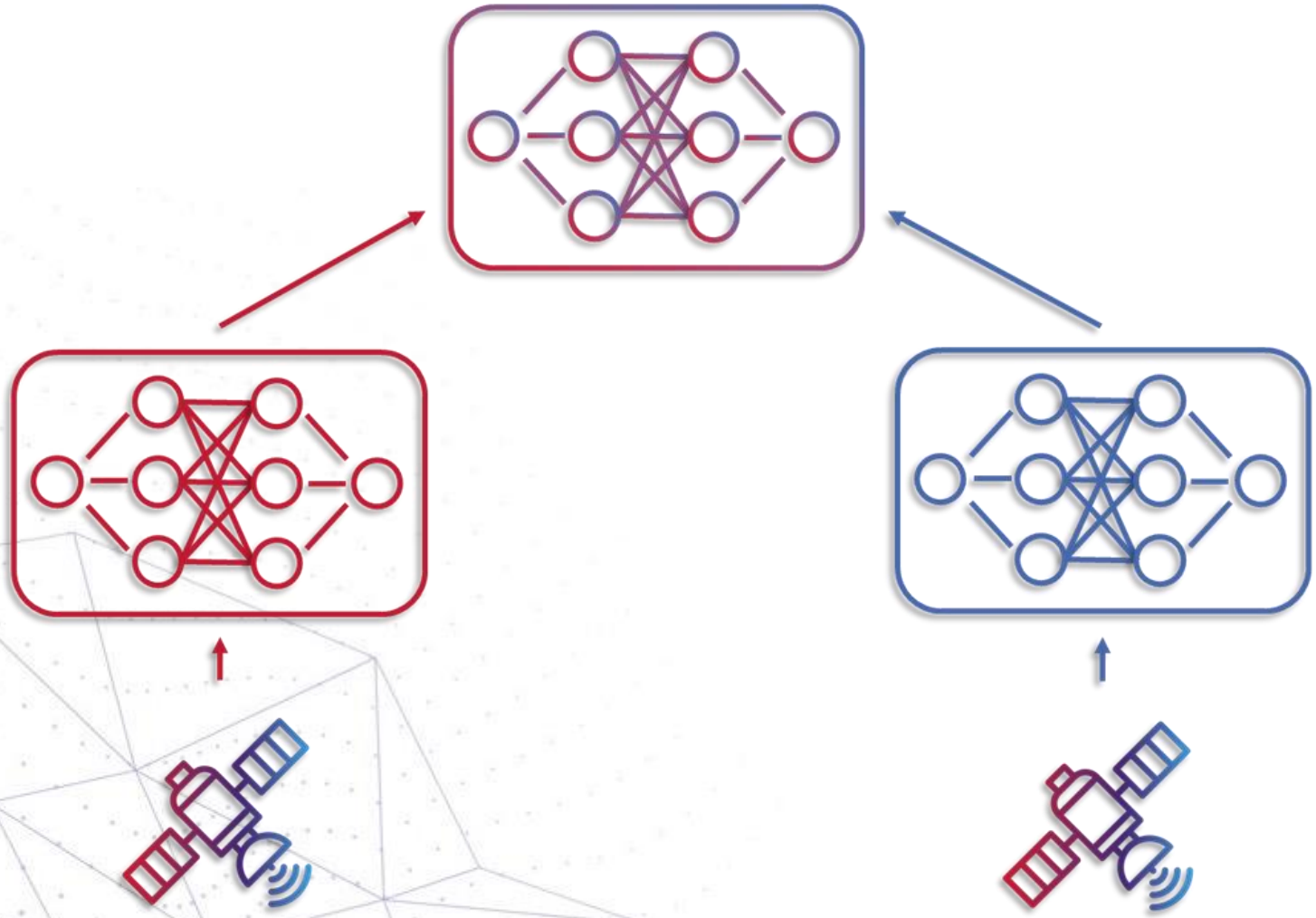
Sharing models, not data



Inter-satellite communication only

How does Federated Learning work?

Sharing models, not data

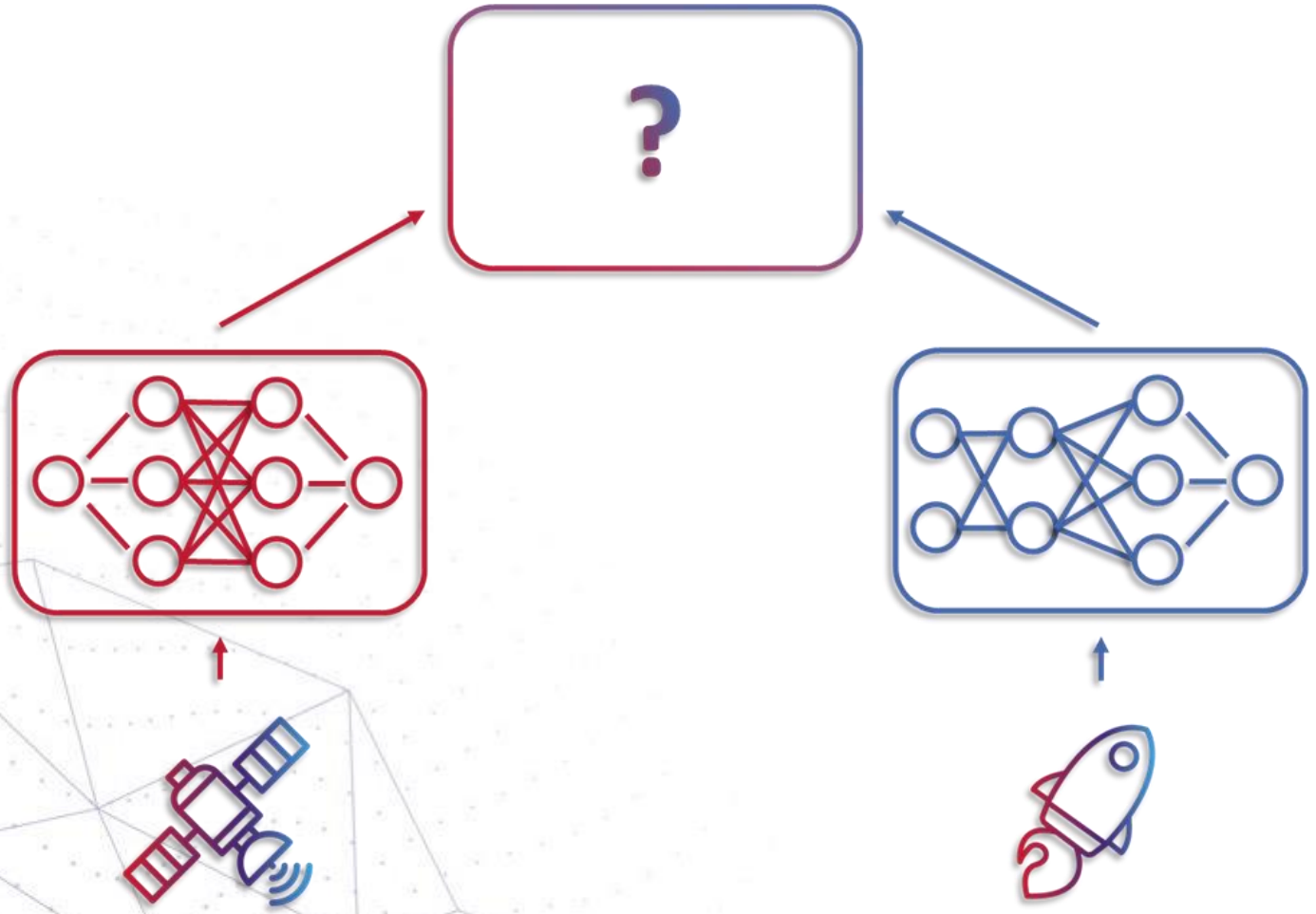


Global Aggregation
One joint model

Local Machine Learning
One model on each satellite

Homogeneous Satellites
Same sensors, different data

Federated Learning for heterogeneous swarms

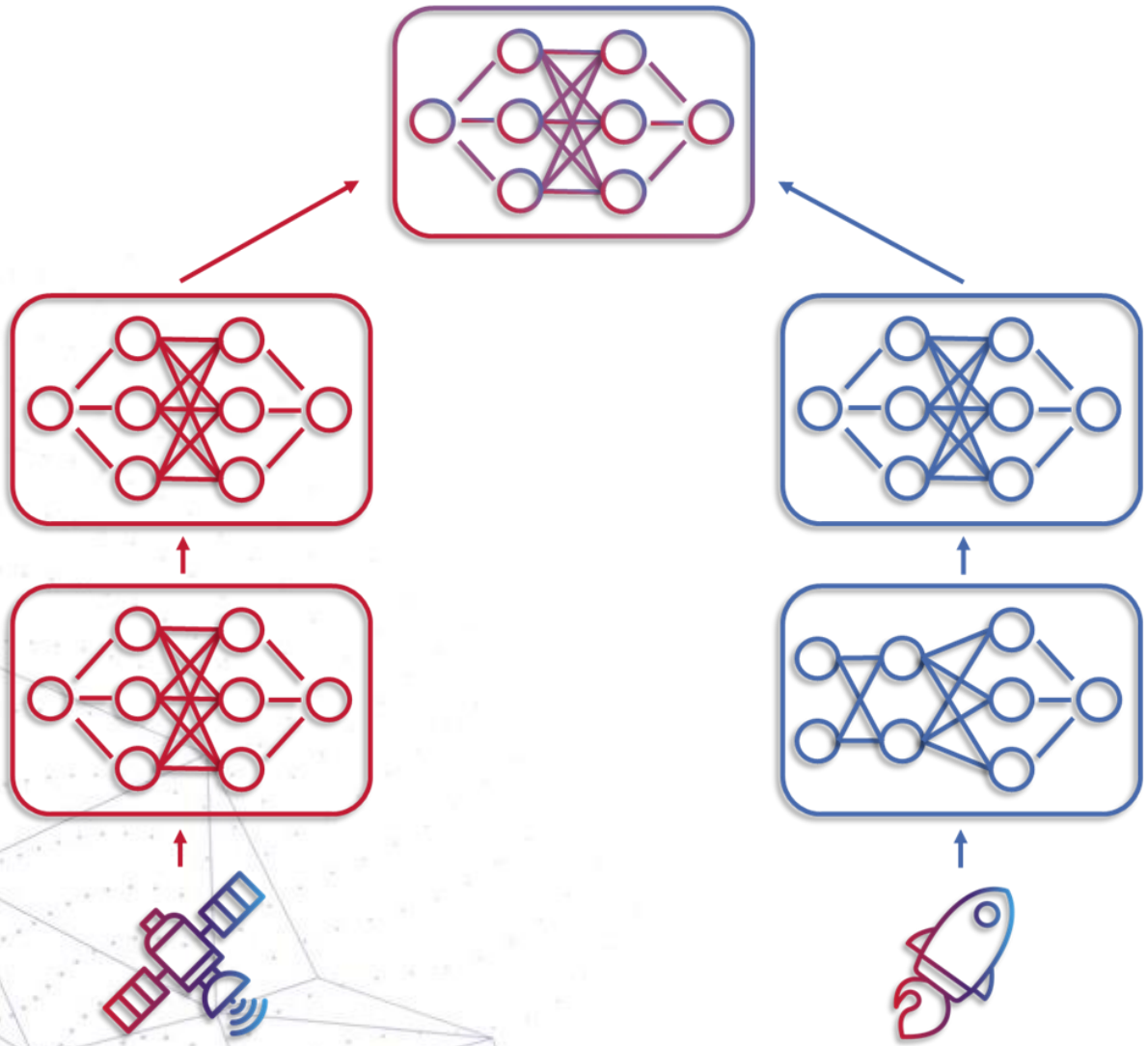


Global Aggregation?
Open question!

Local Machine Learning
One model on each satellite

Heterogeneous Satellites
Different sensors, different data

Two-step Federated Learning for heterogeneous swarms



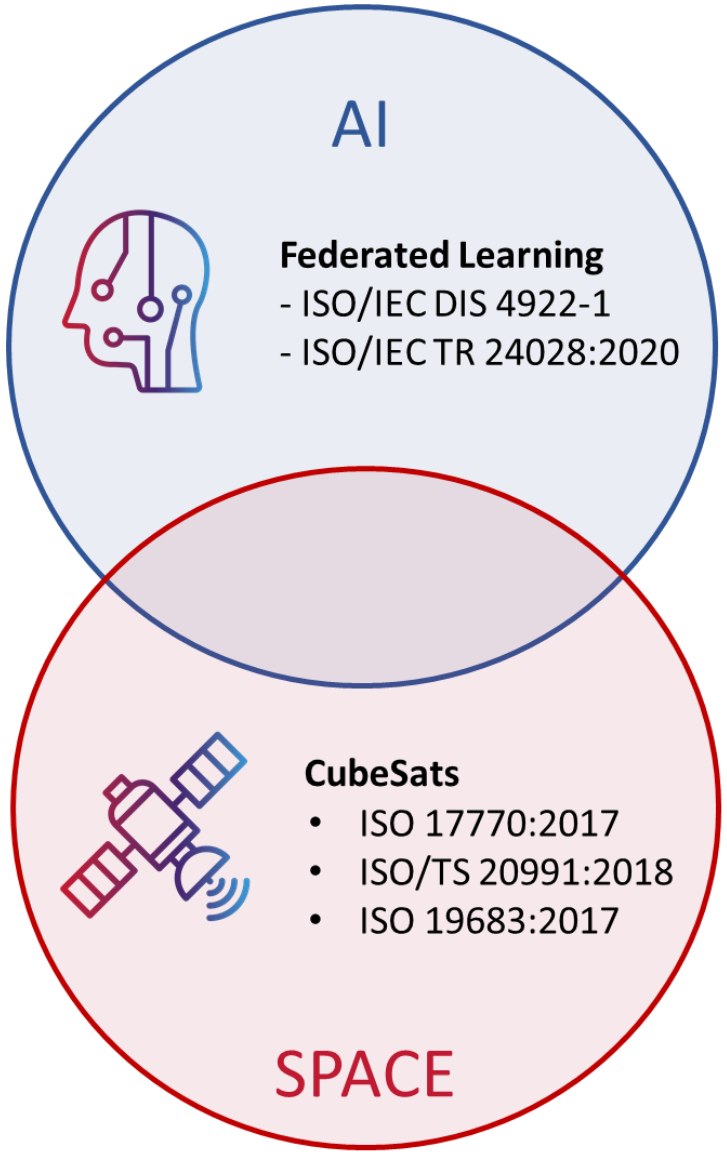
Global Aggregation:
One joint model

Local second step:
Homogeneous models

Local first step:
Heterogeneous models

Heterogeneous Satellites:
Different sensors, different data

Impact on Standardisation



Involvement in Standardisation Committees, Work Groups, Advisory Groups

- **ISO/TC 20/SC 14** – Space systems and operations
- **CEN/CLC JTC 5** – Space
  - **WG 2** – Space Situational Awareness Monitoring
  - **WG 7** – Future activities in space standardisation
- **ISO/IEC JTC 1/SC 42** – Artificial Intelligence
- **CEN-CENELEC JTC 21** – Artificial Intelligence

Parallel Computing and Optimisation Group

Contact:

Maria Hartmann
PhD Student
maria.hartmann@uni.lu

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@SnT_uni_lu

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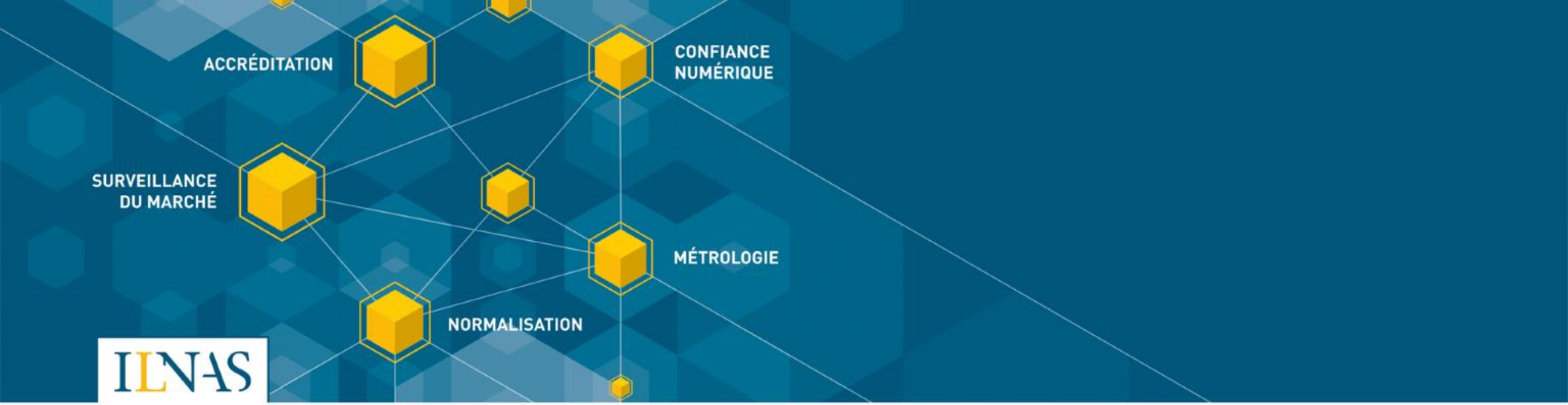
ILNAS

Remise du trophée
“ILNAS Standardization & Innovation Award 2022”

INTERVENANTS

Dr. Jean-Philippe HUMBERT
Adjoint à la Direction
ILNAS

Mme Anika LEY
Gestionnaire de projets
ILNAS/OLN



Journée mondiale de la normalisation

Présentation du prix
« ILNAS Standardization & Innovation Award 2022 »

14 Octobre 2022

Anika LEY – Gestionnaire de projets, ILNAS

L’intérêt de la normalisation pour le domaine de l’innovation et de la recherche

Les croisements et échanges bidirectionnels entre les domaines de la normalisation technique et de la recherche et de l’innovation offrent de nombreux avantages :

L’intégration des résultats de projets de recherche et d’innovation dans le domaine normatif permet une **dissémination plus large** de ces derniers ainsi que leur **reconnaissance** dans des documents de référence

La prise en compte du domaine normatif et de ses derniers développements, dans les différents projets de recherche, permet d’enrichir **l’état de l’art** du domaine concerné, tout en suivant ses avancées dans **l’intérêt du marché**, facilitant ainsi une **comparaison** directe avec les **progrès de la recherche**

L’identification de nouvelles **opportunités de collaboration** scientifiques et commerciales

Rassurer le marché et **faciliter l’adoption et l’acceptation** de nouvelles technologies

Services offerts pour soutenir l'innovation et la recherche

Prestations de conseil

❑ **Veilles normatives ciblées**

Identification des normes et comités techniques de normalisation pertinents afin de faciliter la préparation de projets de recherche et/ou l'exécution de Work Packages dédiés en relation

❑ **Support pour candidats "Horizon Europe"**

La normalisation a été identifiée comme un outil essentiel pour atteindre les objectifs d'Horizon Europe

Ainsi, la normalisation ajoute de la valeur aux propositions et peut améliorer leurs chances d'être sélectionnées pour un financement

L'ILNAS peut offrir son assistance dans la préparation de propositions en identifiant des opportunités d'intégration de la normalisation technique au sein des projets

Mise à disposition de normes

❑ **Achat de normes à un prix préférentiel**

Réductions de prix sur le catalogue de normes (hors normes DIN) aux établissements de recherche + aux start-ups

❑ **Stations de lecture**

Formations et sensibilisations

❑ **Formations**

L'ILNAS offre des formations (en ligne et en présentiel) sur la normalisation technique et la participation active dans le processus d'élaboration des normes

❑ **Sessions d'information sur la normalisation technique**

ILNAS Standardization & Innovation Award

…pour récompenser les organisations ou personnes ayant intégré avec succès les normes dans leurs projets de recherche ou d'innovation

04 mai 2022
Lancement

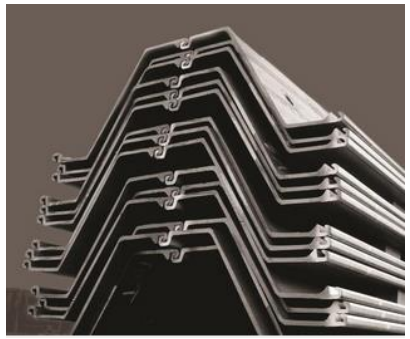
15 juillet 2022
Fin de période de dépôt de candidatures

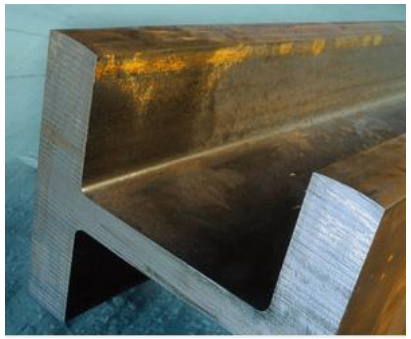
14 octobre 2022
Cérémonie de remise du prix

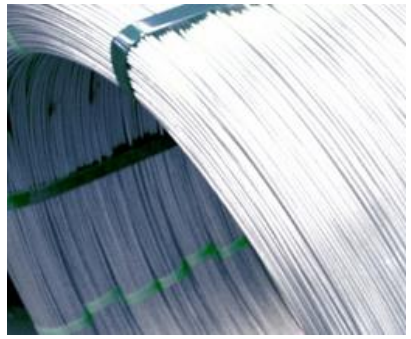
Lauréat 2022

Quelques indices...

Création en 2006







Lauréat 2022

Quelques indices...

Comités de normalisation/techniques concernés

CEN/TC 250/SC 3 - Eurocode 3 : Design of steel structures

- CEN/TC 250/SC 3/WG 1 - Evolution of EN 1993-1-1 - General rules for buildings

Lauréat 2022

ArcelorMittal Steligence® Global R&D

Félicitations !

High strength steels for the design of steel structures

HSS enable lighter, thinner and stronger elements. They allow the design of efficient, cost-effective and sustainable structures.

Project summary

Collaboration between academia and industry → possible to test experimentally HSS and to extend the design rules to these innovative materials

New generation of EN 1993-1-1, steel grades up to S700 for hot rolled products of structural steels are now covered (versus up to S460 previously)

Challenge & Innovation

Extending the scope of applications of the design rules to cover new materials

If not, their use in construction would be strongly restricted

HSS to face climate change and the growing scarcity of raw materials

- → use less material for the same loading
- → reduce the environmental footprint of the structure (while being cost-effective and safe)

Impact with normalization

ArcelorMittal Luxembourg:
Hot rolled steel sections and merchant bars
for the construction sector

Over the last couple of years, the company has developed high strength steels for such products

EN1993-1-1 is development → encourage the manufacture and marketing of such innovative products

S460 → S700

Eurocode 3 : Design of steel structures (Part 1-1 : general rules & rules for buildings)

CEN/TC250/SC3
CEN/TC250/SC3/WG1

ArcelorMittal

Merci à tous les experts impliqués dans la normalisation technique.