WHITE PAPER

TRUSTWORTHINESS IN ICT, AEROSPACE, AND CONSTRUCTION APPLICATIONS

SCIENTIFIC RESEARCH AND TECHNICAL STANDARDIZATION

Version 1.0 · October 2023
ISBN 978-99987-869-7-4

TRUSTWORTHINESS IN ICT, AEROSPACE, AND CONSTRUCTION APPLICATIONS

SCIENTIFIC RESEARCH AND TECHNICAL STANDARDIZATION

Luxembourg, October 2023

ILNAS

Institut Luxembourgeois de la Normalisation, de l'Accréditation, de la Sécurité et qualité des produits et services

ANEC

Agence pour la Normalisation et l'Economie de la Connaissance

UNIVERSITÉ DU LUXEMBOURG

SnT

Foreword

It is now well established that Information and Communication Technology (ICT) is not only a critical component of our daily lives, but also of a great deal of other technical domains in commerce and industry. Indeed, the digitization of information, imaging, technical schematics, and many other commercial and industrial artefacts, combined with information processing capabilities and almost instant communications underlies the automation or robotization of systems and tasks, leading to gains in accuracy, efficiency and quality, for instance.

This newfound reliance on ICT poses questions on the overall trustworthiness of these ICT-supported systems, such as: How can we be sure that they are truly reliable? Can this even be defined in such a way that it can be evaluated?

Elements that support answering this question can be found in the fields of technical standardization on one hand and scientific research on the other, and it is particularly interesting to examine what is, or can be, found at the intersection of these two. In terms of technical standardization, ILNAS (the *Institut luxembourgeois de la normalisation, de l'accréditation, de la sécurité et qualité des produits et services*) - the national standards body of Luxembourg - has been executing the country's National Standardization Strategy 2020-2030[1], with a view towards fostering a national normative culture. On the side of scientific research, the Interdisciplinary Centre for Security, Reliability and Trust (SnT) of the University of Luxembourg has been conducting cutting-edge work recognized at the international level in fields ranging from big data and artificial intelligence to satellite swarms, covering many different facets of trust in ICT.

One of the national standardization strategy's essential components is bringing the research and standardization communities closer together, so that, in one direction, research can feed state-of-the-art results in technical standards, and in the other direction, standards can guide researchers with technical specifications. The current strategy, running from 2020 to 2030, covers three important sectors for the Luxembourg's economy - ICT, Construction and Aerospace - and in order to tackle them from a research standpoint, a partnership between ILNAS and the University of Luxembourg has been established, giving birth to the research program "Technical Standardization for Trustworthy ICT, Aerospace, and Construction (2021-2024)[2]".

1 https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/strategie-normative-luxembourgeoise-2020-2030.html

2 https://ilnas-snt.uni.lu/

Concretely, this program is centered on the activities of three PhD students within the University of Luxembourg, who are invited to discover, leverage, and contribute to technical standardization during their PhD studies. Their research topics are tied respectively to each of the three major domains mentioned in the national strategy. The program's format follows in the footsteps of its predecessor, *"Normalisation technique pour une utilisation fiable dans le domaine 'Smart ICT' (2017-2020)*[3]*"*, which yielded a number of interesting results. These include, among others, the publication of a white paper on data protection and privacy[4] and a technical report on standards gap analyses[5], and the earning by one of that program's students of CEN-CENELEC's "standards + innovation award" in the "young researcher" category in 2021[6].

The current white paper is one of the first outcomes of the new program. It shows how research and technical standardization can shed some light on what ICT trustworthiness means in each topic, all while encouraging not just the research community, but all national market actors of Luxembourg to get involved in technical standards activity, for their own benefit, and that of the economy.

Jean-Marie REIFF
Director
ILNAS

Jean-Philippe HUMBERT
Deputy Director
ILNAS

Pascal BOUVRY
Full Professor, Special Advisor to the Rector
University of Luxembourg

3 https://portail-qualite.public.lu/fr/normes-normalisation/education-recherche/normalisation-recherche.html#prog-2017-2020

4 https://portail-qualite.public.lu/fr/publications/normes-normalisation/etudes/ilnas-white-paper-data-protection-privacy-smart-ict.html

5 https://portail-qualite.public.lu/fr/publications/normes-normalisation/etudes/technical-reports-gap-analysis-between-scientific-research-and-technical-standardization.html

6 https://www.cencenelec.eu/get-involved/research-and-innovation/cen-and-cenelec-activities/s-i-awards/list-of-nominees-2021/

Acknowledgements

The working group involved in the preparation of this white paper is:

Name of the contributor	Institution/Organization
Mr. Jean-Marie REIFF	ILNAS
Dr. Jean-Philippe HUMBERT	ILNAS
Prof. Dr. Pascal BOUVRY	SnT
Dr. Grégoire DANOY	SnT
Dr. Mohammed ALSWAITTI	SnT
Ms. Lena Maria HARTMANN	SnT
Ms. Hedieh HADDAD	SnT
Mr. Manuel COMBARRO SIMON	SnT
Dr. Lucas CICERO	ILNAS
Dr. Jean LANCRENON	ILNAS
Mr. Nicolas DOMENJOUD	ILNAS
Mrs. Leslie FOUQUERAY	ILNAS
Mrs. Natalia VINOGRADOVA	ANEC GIE
Mr. Ruddy ENGUEHARD	ANEC GIE

Table of contents

Abbreviations

AI	Artificial Intelligence
ANEC GIE	*Agence pour la Normalisation et l'Economie de la Connaissance*
AOI	Area of Interest
API	Application Programming Interface
BIM	Building Information Modelling
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
COTS	Commercial off-the-shelf
EC	European Commission
EO	Earth Observation
ETSI	European Telecommunications Standards Institute
EU	European Union
FL	Federated Learning
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IFC	Industry Foundation Classes
ILNAS	*Institut luxembourgeois de la normalisation, de l'accréditation, de la sécurité et qualité des produits et services*
IoT	Internet of Things
ISO	International Organization for Standardization
ITS	Intelligent Transport System
ITU	International Telecommunications Union
ITU-T	ITU's Telecommunication standardization sector
LBS	Location-Based System
ML	Machine Learning
NNEF	Neural Network Exchange Format
NSGA	Non-dominated Sorting Genetic Algorithm
ONNX	Open Neural Network Exchange
OGC	Open Geospatial Consortium
SIMS	Satellite Image Mosaic Selection
SnT	Interdisciplinary Centre for Security, Reliability and Trust
TC	Technical Committee
TR	Technical Report
TS	Technical Specification
UML	Unified Modeling Language
UTM	Universal Transverse Mercator
WGS84	World Geodetic System 1984

List of Figures

List of Tables

1

Trustworthiness, research, and standardization

1. Trustworthiness, research, and standardization

1.1. A natural development chain

The development of trustworthy solutions to address challenges has natural ties to two important worlds: those of technical standardization and scientific research. First, society - in the form of individuals, organizations, industries, etc. - regularly faces problems that need to be solved to make general progress. In turn, research, whether public or private, tackles those problems, searching first for theoretical answers, next demonstrating prototypes or proofs-of-concept, and finally converting findings into workable solutions. Technical standardization is naturally incorporated into this process to encode these solutions in manners that stakeholders achieve consensus on as being optimal baselines to be broadly applied, in particular to ensure more transparency and impartiality. Finally, the overall process confers a level of trustworthiness to standardized products, services, or processes when they are actually used in the field. An illustration of this development chain is given in Figure 1.

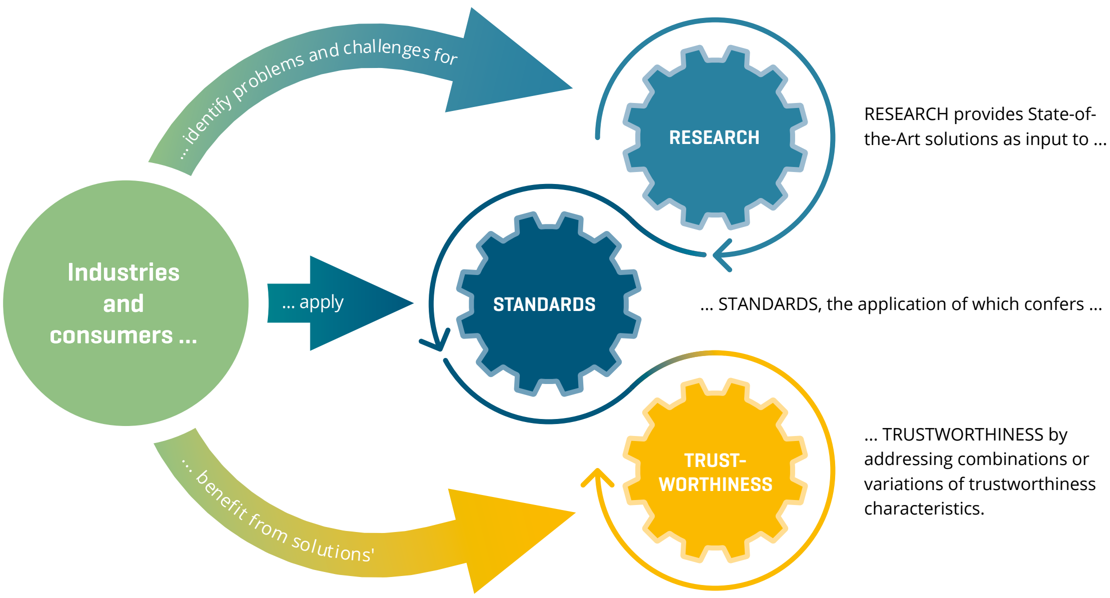

Figure 1: Relations between scientific research, technical standardization, trustworthiness, and market players

In the Grand Duchy of Luxembourg, a partnership to explore more intricately the links between standardization and research in support of trustworthiness was established between the *Institut luxembourgeois de la normalization, de l'accréditation, de la sécurité et qualité des produits et services*, or ILNAS[7] - Luxembourg's national standards body - and the University of Luxembourg[8]. The partnership, entitled "Technical Standardization for Trustworthy ICT, Aerospace, and Construction (2021-2024)"[9], involves bringing research and standardization closer together via the work of three PhD students. As the first major outcome of the program, this white paper is a prospective look at how standards relate to trustworthiness characteristics identified in three use cases, where each use case corresponds to a PhD student's research topic and to one of the identified growth sectors of Luxembourg's National Standardization Strategy 2020-2030[10].

7 https://portail-qualite.public.lu/fr/acteurs/ilnas.html

8 https://www.uni.lu/en/

9 https://portail-qualite.public.lu/fr/normes-normalisation/education-recherche/normalisation-recherche.html#prog-2017-2020

10 https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/strategie-normative-luxembourgeoise-2020-2030.html

1.2. Three growth sectors, three use cases

The national standardization strategy focuses on Information and Communication Technologies (ICT), Construction, and Aerospace (with a focus on the Space sector in particular).

Regarding ICT, Luxembourg enjoys a particularly vibrant ecosystem, with many national and governmental initiatives pushing for a more and more digitized society[11]. On the topic of Construction, the sector has over 4,500 companies[12] in the national market, covering all aspects: study and design, construction of utility networks, building completion and finishing work, etc. and making it a true national economic powerhouse. Finally, concerning the Aerospace sector, in roughly four decades, Luxembourg has become a predominant actor in Space business in Europe, by for instance becoming the first European actor to offer a legal framework for space resource exploration and usage[13].

Historically, ICT was the first growth sector to be incorporated to a national standardization strategy[14], with Construction and Aerospace having been added afterwards. Thus, ICT plays a somewhat more prominent role in the research program as well. Furthermore, ICT is now an important component in other domains, including Construction and Aerospace. Accordingly, ICT also underlies all three of the use cases which each correspond to a growth sector (see Chapter 3):

- The first use case (ICT, see Section 3.1) studies the efficient creation of mosaics of satellite images for earth observation, and explores how to optimize this, in particular with multiple image providers;
- The second use case (Construction, see Section 3.2) examines optimization aspects in Building Information Modelling; and
- The third use case (Space, see Section 3.3) deals with the use of Artificial Intelligence at the service of swarms of nanosatellites.

The description of each use case shows where and how trustworthiness is important, and how standards can support in achieving it.

1.3. Trustworthiness characteristics

In order to pinpoint how and where standards support trustworthiness in each use case, it is necessary first to identify a usable definition of trustworthiness itself.

Common intuition essentially views the trust in someone or something as a form of belief, hope, or confidence that that someone or something is reliable for some purpose. For instance, the online Merriam-Webster dictionary considers trust as being the “assured reliance on the character, ability, strength, or truth of someone or something”[15]. This yields trustworthiness as being a quality that someone or something can be trusted, or is “worthy of confidence”[16].

11 https://luxembourg.public.lu/fr/investir/secteurs-cles/ict.html
12 https://statistiques.public.lu/fr/publications/series/repertoire-entreprises/2020/repertoire-2020.html
13 https://space-agency.public.lu/en/space-resources/the-initiative.html
14 As early as 2014, see https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/strategie-normative-2014-2020.html
15 https://www.merriam-webster.com/dictionary/trust#dictionary-entry-1
16 https://www.merriam-webster.com/dictionary/trustworthiness

In technical standardization, precise definitions have considerable importance, since the documents that are produced have the end purpose of being conformed to in a precise manner. Hence, given that considerations of trust and trustworthiness are found more and more frequently in ICT standards, it was viewed as useful by the technical standardization committee ISO/IEC JTC 1 *Information Technology*[17] to provide an adequate definition for its many subcommittees. As a result, a dedicated working group of JTC 1 - WG 13 Trustworthiness - was formed to investigate these matters.

As the use cases are all ICT-supported, for our purpose it is convenient to use a recently published technical specification prepared by working group WG 13, and published by ISO/IEC JTC 1. The technical specification ISO/IEC TS 5723:2022 *Trustworthiness – Vocabulary*[18] not only gives a definition of trustworthiness overall (combining the various sub-definitions of the document, it becomes the *"ability to meet stakeholders' expectations in a way that can be checked for correctness by a person or tool")*, it also recognizes that trustworthiness in ICT may arise in different ways depending on the underlying domain. Thus, a number of characteristics of trustworthiness were identified. We shall see which of these apply in the case studies being researched. Table 1 below is almost directly extracted from ISO/IEC TS 5723:2022, via the ISO Online Browsing Platform[19] (some simplifications were brought to the text to improve readability).

Characteristic	Simplified definition
Accountability	State of being answerable for actions, decisions, and performance
Accuracy	Measure of closeness of results of observations, computations, or estimates to the true values or the values accepted as being true
Authenticity	Property that an entity is what it claims to be
Availability	Property of being accessible and usable on demand by an authorized entity
Controllability	Property of a system that allows a human or another external agent to intervene in the system's functioning
Information security	Preservation of confidentiality, integrity and availability of information
Integrity (of data and of systems)	For data: property whereby data have not been altered in an unauthorized manner since they were created, transmitted, or stored For systems: property of accuracy and completeness
Privacy	Freedom from intrusion into the private life or affairs of an individual
Quality (of data and of systems)	For data: degree to which the characteristics of data satisfy stated and implied needs when used under specified conditions For systems: degree to which a set of inherent characteristics of an object fulfils requirements
Reliability (from a cybersecurity point of view and a system point of view)	Cybersecurity point of view: property of consistent intended behaviour and results For systems: ability of an item to perform as required, without failure, for a given time interval, under given conditions

17 https://www.iso.org/committee/45020.html

18 https://www.iso.org/standard/81608.html

19 https://www.iso.org/obp/ui/en/#iso:std:iso-iec:ts:5723:ed-1:v1:en

Resilience (from a governance point of view and a system point of view)	Governance point of view: ability to anticipate and adapt to, resist, or quickly recover from a potentially disruptive event, whether natural or man-made For systems: capability of a system to maintain its functions and structure in the face of internal and external change, and to degrade gracefully when this is necessary
Robustness	Ability of a system to maintain its level of performance under a variety of circumstances
Safety	Property of a system such that it does not, under defined conditions, lead to a state in which human life, health, property, or the environment is endangered
Security	Resistance to intentional, unauthorized act(s) designed to cause harm or damage to a system
Transparency (of information and of systems)	For information: open, comprehensive, accessible, clear and understandable presentation of information For systems: property of a system or process to imply openness and accountability
Usability	Extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use

Table 1: Characteristics of trustworthiness according to ISO/IEC TS 5723:2022

1.4. Use case mapping between trustworthiness, research and standards

In each of the use cases, the reader will find, alongside the description of the research being conducted, one or more tables that show how various aspects, questions or topics tackled by the use case are related to, or support, a trustworthiness characteristic and also examples of standards that can be used. This illustrates how standards can play a role in many of the steps underlying an applied research question, to achieve trustworthiness.

1.5. Outline of the white paper

Chapter 2 is an overview of technical standardization, its objectives, its added-value for societal and economic growth, and how it is accounted for in Luxembourg. Chapter 3 details the three use cases of the research program, showcasing the links between standardization and research in support of trustworthiness. Finally, section Conclusion and outlook concludes the white paper and the Annex simply gathers together a list of the standardization committees encountered along the way.

2

Technical standardization

2. Technical standardization

2.1 Technical standards

The European Regulation (EU) N°1025/2012 on European standardization[20] gives the following definition of a standard:

"a technical specification, adopted by a recognized standardization body, for repeated or continuous application, with which compliance is not compulsory […]"

Standards are meant to bring solutions to recurrent technical and business problems, on a broad scale, and may apply to products, services, and processes. The World Trade Organization[21] has listed a set of fundamental principles that international standards and standards development should adhere to in order to be adequate. These are:

- **Transparency of technical work programs.** All essential information regarding current work programs, as well as on proposals for standards, guides and recommendations under consideration and on the results should be made easily accessible to all interested parties;
- **Openness in participation.** Membership of an international standards body should be open on a non-discriminatory basis to relevant bodies;
- **Impartiality and consensus.** All relevant bodies should be provided with meaningful opportunities to contribute to the elaboration of an international standard so that the standard development process will not give privilege to, or favor the interests of, a particular supplier, country or region. Consensus procedures should be established that seek to take into account the views of all parties concerned and to reconcile any conflicting arguments;
- **Effectiveness and relevance.** International standards need to be relevant and to effectively respond to regulatory and market needs, as well as scientific and technological developments in various countries. They should not distort the global market, have adverse effects on fair competition, or stifle innovation and technological development. In addition, they should not give preference to the characteristics or requirements of specific countries or regions when different needs or interests exist in other countries or regions. Whenever possible, international standards should be performance based rather than based on design or descriptive characteristics;
- **Coherence.** In order to avoid the development of conflicting international standards, it is important that international standards bodies avoid duplication of, or overlap with, the work of other international standards bodies. In this respect, cooperation and coordination with other relevant international bodies is essential;
- **Development dimension.** Constraints on developing countries, in particular, to effectively participate in standards development, should be taken into consideration in the standards development process. Tangible ways of facilitating developing countries' participation in international standards development should be sought.

20 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32012R1025

21 https://www.wto.org/english/tratop_e/tbt_e/principles_standards_tbt_e.htm

The benefits of applying technical standards are numerous:

- **Quality and security.** Technical standards are developed primarily to solve problems and increase the quality of the target solution. A standardized product carries with it the knowledge of good practices from a large pool of experts. Quality is of utmost importance in many fields, for instance whenever there are effects on health and safety;
- **Interoperability and trade facilitation.** Standardized products support the achievement of mutual understanding through the use of common technical languages to describe problems, solutions, and requirements. Thus, they favor interoperability, exchange, and encourage the interchangeability of solutions;
- **Competitiveness.** Adhering to a recognized standard in a field gives a competitive edge, owing to the qualitative benefits that standards provide. This confers a certain level of economic product protection;
- **Efficiency.** Standards are developed with a view towards bringing the most broadly applicable and effective solution in mind, while preserving a large degree of flexibility. This translates to convenience of use;
- **Societal progress.** Standardized solutions can help disseminate good practices with built-in considerations for emerging important – and world-wide – challenges, such as environmental protection and the management of diversity.

2.2. Major international and European standards organizations

The overall worldwide standards landscape is quite complex, because it contains major international and regional standardization bodies in addition to thousands of industrial fora, consortia, associations, etc. that develop technical specifications and other deliverables. Moreover, all national standardization bodies can also issue technical specifications and standards, which increases the source diversity of documentation. Nevertheless, for the purpose of this document, only the six bodies recognized by the European Commission (European Regulation (EU) N°1025/2012) are considered, three at the international level and three at the European level.

The three official international ones are:

- the International Organization for Standardization (ISO)[22];
- the International Electrotechnical Commission (IEC)[23];
- the International Telecommunication Union's Telecommunication Standardization Sector (ITU-T)[24].

The three official European Standardization Organizations (ESOs) are:

- the European Committee for Standardization (CEN)[25];
- the European Committee for Electrotechnical Standardization (CENELEC)[26];
- the European Telecommunications Standards Institute (ETSI)[27].

The governance system for ISO, IEC, CEN, and CENELEC organizes membership per state, while that of ITU and ETSI does so per organization. Thus, any given state involved in ISO, IEC, CEN, or CENELEC has one or more National Standards Bodies (NSBs) representing them within these organizations. Often, these national bodies are also in charge of developing national-level standards. In Luxembourg, the NSB is ILNAS (see Paragraph 2.3.1), which is also a member of ITU-T and ETSI, see Figure 2.

22 https://www.iso.org/home.html
23 https://iec.ch/homepage
24 https://www.itu.int
25 https://www.cencenelec.eu/about-cen/
26 https://www.cencenelec.eu/about-cenelec/
27 https://www.etsi.org/

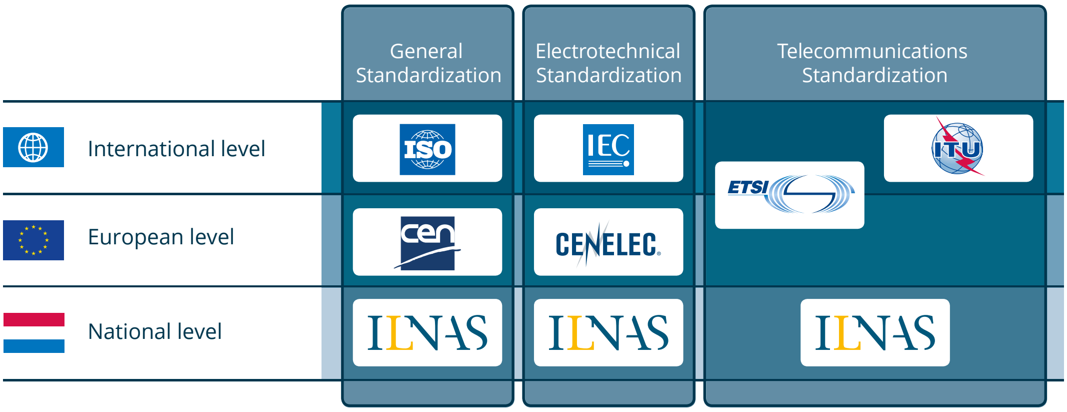

Figure 2: Relative positioning of the main standards developing organizations

2.2.1. ISO and IEC Standardization Committees

ISO is the world's dominant developer and publisher of International Standards in terms of scope. It has over 24,000 standards published and more than 4,000 standards under development[28]. ISO is in charge of developing International Standards for all industry sectors.

IEC prepares and publishes International Standards for all electrical, electronic and related technologies – collectively known as "electrotechnical".

To prevent an overlap in standardization work related to information technology, ISO and IEC formed a Joint Technical Committee in 1987 known as ISO/IEC JTC 1 *Information technology*[29]. It has taken a leading role in ICT standardization in the last few years with the creation of working groups and technical subcommittees directly responsible for the development of ICT International Standards.

2.2.2. CEN and CENELEC Standardization Committees

CEN and CENELEC are two official European Standards Organizations (ESOs) closely collaborating through a common CEN-CENELEC Management Centre since 2010. They are notably in charge of developing ICT standards at the European level. Even if most of the ICT-related topics are being tackled at the international level by ISO/IEC JTC 1, complying with the "Vienna Agreement" set up between CEN and ISO, as detailed below, CEN and CENELEC have technical committees and additional other groups active in different areas of the ICT sector directly under their supervision[30]. The standardization activities of CEN and CENELEC are detailed in an annual common Work Program[31], which was published in January 2023 for the year 2023.

2.2.3. ETSI - European Telecommunications Standards Institute

ETSI is a leading standardization organization for ICT standards fulfilling European and global market needs. The European Union officially recognizes ETSI as an ESO. ETSI is active in ten ICT "sectors", regrouping a number of technical committees and covering a wide range of technologies, namely: Home and Office, Better living with ICT,

28 https://www.iso.org/iso-in-figures.html

29 https://www.iso.org/committee/45020.html

30 The list of all CEN/CENELEC Joint Technical Committees (JTCs) can be found here https://standards.cencenelec.eu/dyn/www/f?p=CEN:6

31 https://www.cencenelec.eu/media/CEN-CENELEC/News/Publications/2023/workprog2023.pdf

Content Delivery, Networks, Wireless Systems, Transportation, Connecting Things, Interoperability, Public Safety, and Security[32]. The standardization activities of ETSI are detailed in an annual Work Program[33], whose last edition covers the 2023/2024 period.

2.2.4. ITU-T - International Telecommunication Union - Telecommunication Standardization Sector

The International Telecommunication Union - Telecommunication Standardization Sector (ITU-T) is an "intergovernmental public-private partnership organization" which brings together experts from around the world to develop international standards known as ITU-T Recommendations, which cover defining elements in the global infrastructure of ICT. It is currently composed of 11 Study Groups working on different aspects of ICT[34].

2.2.5. Cooperation between standards-developing organizations

Several bridges exist between the national, European and international standardization organizations in order to facilitate the collaboration and coordination of standardization work in the different fields. Indeed, in order to ensure transparency in the work, prevent standards duplication, and avoid conflicting requirements, agreements have been established between international and European standardization organizations.

In 1991, ISO and CEN signed the Vienna Agreement[35], which is based on the following guiding principles:

- Primacy of international standards and adoption of ISO Standards at the European level (EN ISO);
- Work at the European level (CEN), if there is no interest at the international level (ISO);
- When a given project undergoes parallel development, procedures are in place ensuring standardization documents of common interest are approved by both organizations (ISO and CEN).

Similarly, CENELEC and IEC signed the Dresden Agreement in 1996 with the aim of developing intensive consultations in the electrotechnical field. This agreement was superseded by the Frankfurt Agreement[36] in 2016 with the aim to simplify the parallel voting processes, and increase the traceability of international standards adopted in Europe thanks to a new referencing system. It is intended to achieve the following guiding principles:

- Development of all new standardization projects by IEC (as much as possible);
- Work at the European level (CENELEC), if there is no interest at the international level (IEC);
- When a given project undergoes parallel development, ballots for relevant standardization documents are organized simultaneously by both organizations (IEC and CENELEC).

Under both agreements, 34% of all European standards ratified by CEN, as well as 74% of those ratified by CENELEC, are respectively identical to ISO or IEC standards[37]. In that respect, the European and international organizations do not duplicate work.

Similarly, ITU-T and ETSI have agreed on a Memorandum of Understanding (MoU)[38] in 2000, lastly renewed in 2016, that paves the way for European regional standards, developed by ETSI, to be recognized internationally.

32 https://www.etsi.org/technologies
33 https://www.etsi.org/e-brochure/Work-Programme/2023-2024/mobile/index.html#p=1
34 https://www.itu.int/en/ITU-T/studygroups/2022-2024/Pages/default.aspx
35 https://boss.cen.eu/media/CEN/ref/vienna_agreement.pdf
36 https://www.cencenelec.eu/media/Guides/CLC/13_cenelecguide13.pdf
37 https://www.cencenelec.eu/stats/CEN_CENELEC_in_figures_quarter.htm
38 https://www.itu.int/en/ITU-T/extcoop/Documents/mou/MoU-ETSI-ITU-201605.pdf

2.3. ILNAS and ANEC GIE

2.3.1. ILNAS

ILNAS *(Institut luxembourgeois de la normalisation, de l'accréditation, de la sécurité et qualité des produits et services)* is a public administration under the authority of the Minister of the Economy of the Grand Duchy of Luxembourg. Founded in 2008, ILNAS represents a network of competencies relating to quality, safety and conformity of products and services (see Figure 3), and its mission is to support national competitiveness. ILNAS' missions are encoded in national legislation, namely the amended Law of July 4th, 2014, reorganizing ILNAS[39], which was additionally updated in December 2022[40].

Figure 3: The departments of ILNAS

One of ILNAS' missions is to promote technical standardization. As such, it is the Grand Duchy's only National Standards Body.

ILNAS organizes its standardization work according to the 2020-2030 National Standardization Strategy[41], and associated ICT[42], Construction[43], Aerospace[44], and CASCO[45] national technical standardization policies. Overall, the objectives are to raise awareness on the use of technical standards, promote active participation in the development and publication of standards drafts, enhance Luxembourg's international visibility in standardization, and develop strong links between standardization, scientific research and education.

39 https://legilux.public.lu/eli/etat/leg/loi/2014/07/04/n2/jo

40 https://legilux.public.lu/eli/etat/leg/loi/2022/12/23/a686/jo

41 https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/strategie-normative-luxembourgeoise-2020-2030.html

42 https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/politique-luxembourgeoise-pour-la-normalisation-technique-des-tic-2022-2025.html

43 https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/politique-luxembourgeoise-pour-la-normalisation-technique-du-secteur-de-la-construction-2020-2025.html

44 https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/politique-luxembourgeoise-pour-la-normalisation-technique-du-secteur-de-l-aerospatial-2021-2025.html

45 https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/politique-normative-nationale-iso-casco-2022-2030.html

2.3.2. ANEC GIE

The ANEC GIE *(Agence pour la normalisation et l'économie de la connaissance)* is an economic interest group whose partners are the Ministry of the Economy, the *Chambre des métiers*[46] and the *Chambre de commerce*[47]. One of its main roles is to support ILNAS in its standardization missions. In particular, it aids ILNAS in implementing the national standardization strategy 2020-2030 and the linked national standardization policies. In practice, this entails pursuing the following activities:

- Regularly informing the national market of the latest technical standardization developments;
- Actively promoting the use of standards and the benefits of participating in the standards development process;
- Animating trainings on technical standardization in relation to technologies of interest;
- Supporting ILNAS in the production of national deliverables, such as white papers, national technical standardization reports, topic-specific standards analyses, etc.;
- Supporting ILNAS in its efforts to strengthen the ties between technical standardization, scientific research, education, and innovation, namely through research programs between ILNAS and the University of Luxembourg[48], and participation in the MTECH Master's degree (Technopreneurship: mastering smart ICT, standardisation and digital trust for enabling next generation of ICT solutions[49]).

46 https://www.cdm.lu/

47 https://www.cc.lu/

48 https://portail-qualite.public.lu/fr/normes-normalisation/education-recherche/normalisation-recherche.html

49 https://www.uni.lu/fstm-en/study-programs/master-in-technopreneurship/

2.4. Standardization committees relevant to the topics of the research program

Figure 4 illustrates a few of the main technical standardization committees that publish, maintain or are working on the standards or projects that are mentioned in this report. The exact list of technical committees and their scopes can be found in the Annex.

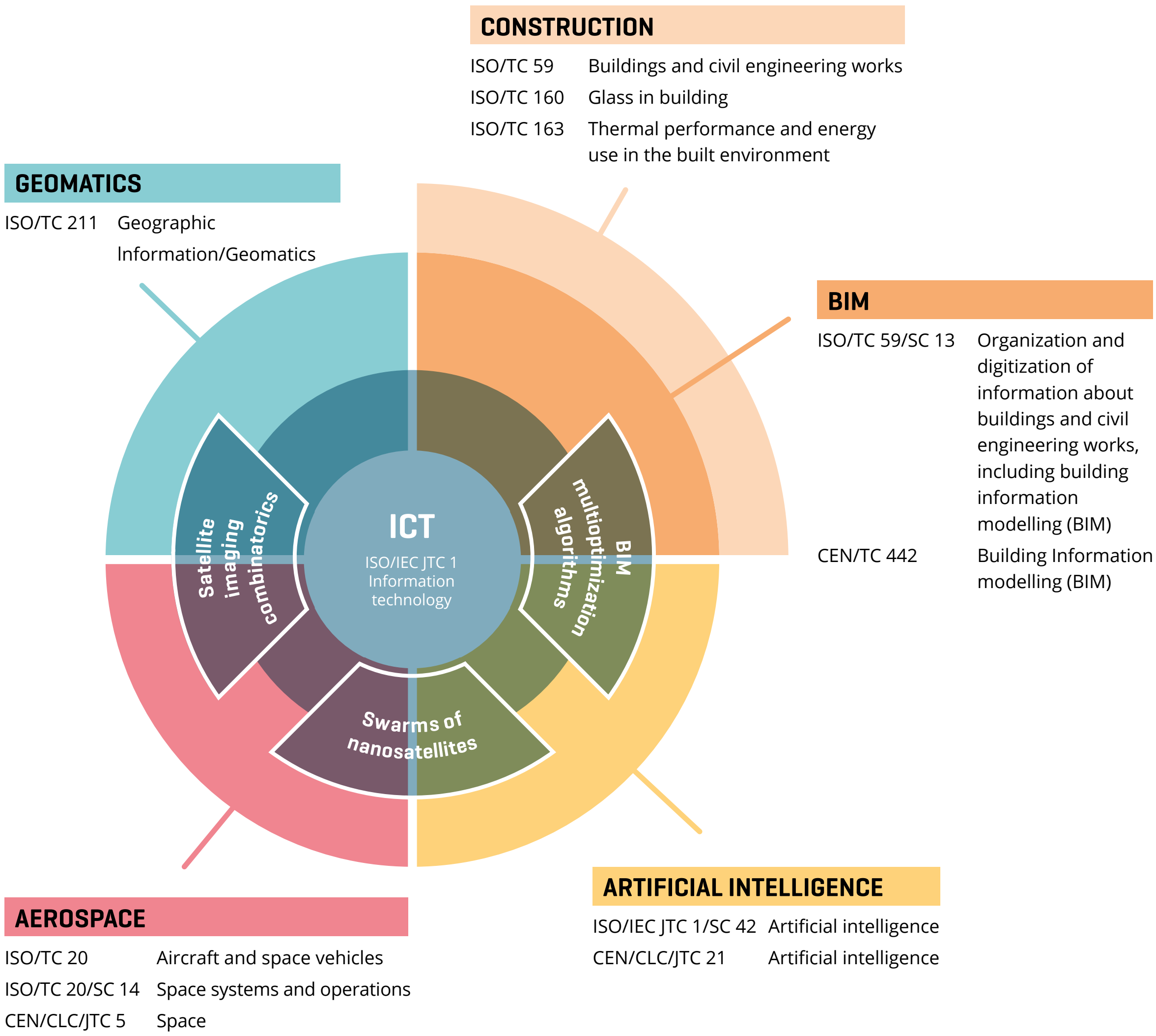

Figure 4: Research subjects with related Technical Committees and their intersections.

2.5. Participating in technical standardization

In its capacity as NSB for Luxembourg, ILNAS (supported by the ANEC GIE) is the gateway to technical standardization for the country in ISO, IEC, CEN, and CENELEC.

2.5.1. Benefits

Participating in technical standards development has multiple advantages:

- **Gain advanced knowledge of future specifications.** Future products in your field may be influenced by a widely accepted standard. Advanced knowledge of this aids in proactively adapting to the market;
- **Shape standards according to your needs and know-how.** Standards are a way to spread your ideas and requirements, not just as a way to remain competitive, but also to enhance the value of your expertise and making it known to a wide range of stakeholders;
- **Gain access to a strategic network of experts.** Participating grants access to a larger pool of technical expertise and knowing who works in standardization sheds further light on current and future interests of partners and competitors.

2.5.2. How to get involved in Luxembourg

ILNAS offers the possibility for nationally established companies to register actively participating delegates within ISO, IEC, CEN, and CENELEC technical committees (and working groups) free-of-charge. ILNAS also offers support and coaching to new delegates, in order to assist them in their standardization needs. Roles held by delegates can range from being an expert that comments and votes on projects to more involved tasks such as proposing new work items and leading the editing of projects. It only depends on the time one wishes to grant to these activities.

The full range of ILNAS' services related to technical standardization in support of the national market can be found on the *Portail Qualité*[50].

50 https://portail-qualite.public.lu/fr/normes-normalisation.html

3

Trustworthiness in ICT-supported application domains: Use cases

3. Trustworthiness in ICT-supported application domains: Use cases

This chapter presents the ICT-supported use cases introduced in Sections 1.1. and 1.2., and shows links to the trustworthiness characteristics discussed in Section 1.3. and technical standardization.

3.1. A combinatorial problem in satellite mosaic image generation

3.1.1. Introduction to satellite imagery

Thanks to the advances in optical sensors and satellite design, the number of satellites dedicated to Earth Observation (EO) has significantly risen in recent years. It has increased more than five times from 2014 with 192 satellites observing the Earth, till 2021 with 971 satellites [1]. This led to the increase in the amount of available satellite imagery as well as in the speed of images' updates. In consequence, new applications using satellite imagery to monitor and study the planet have been developed.

Buying satellite imagery could be a challenging task for small-medium companies or new customers, as they need to understand how different image providers operate in order to be able to use images from different sources. Indeed, if a user is interested in one specific area and only consults one provider it could happen that no images with the required specifications (e.g. cloud coverage, incidence angle, resolution, range of dates) are available. To obtain a result which meets its expectations, the user may need to contact other providers and then combine the results. This task could be complex because image providers can have different ways of describing images and the same image coming from different providers may seem to have different characteristics and thus answering different requirements, leading to the user buying two or more times the same or a similar image. This process can be long and tedious.

To tackle this problem simply and efficiently, the images can be purchased via a satellite image marketplace instead of getting them directly from the providers. A satellite image marketplace is an online platform where the user can get images from several providers. To get the images, the users only need to specify the area of interest (AOI) and the requirements for the images, for example: date ranges, resolution or cloud coverage percentage.

However, using marketplaces only partially addresses the problem since they give access to a larger number of available images but don't combine the results: the users still need to do the exercise by themselves.

Moreover, in certain applications that study large areas, a merging process, called mosaicking, is necessary to cover the full region of interest. In this case, users face the complex problem of selecting the appropriate images and building the mosaic.

3.1.2. Satellite image mosaics

Mosaicking is an important tool in remote sensing that helps organisations obtain a comprehensive view of large areas that cannot be captured by a single satellite image. This technique can be used in many types of applications such as crop classification, environmental monitoring or urban planning.

Practically, mosaicking consists of assembling several images, covering adjacent or overlapping regions, in order to create a uniform and continuous image that shows the entire AOI. Figure 5 shows an example of a mosaic of satellite images.

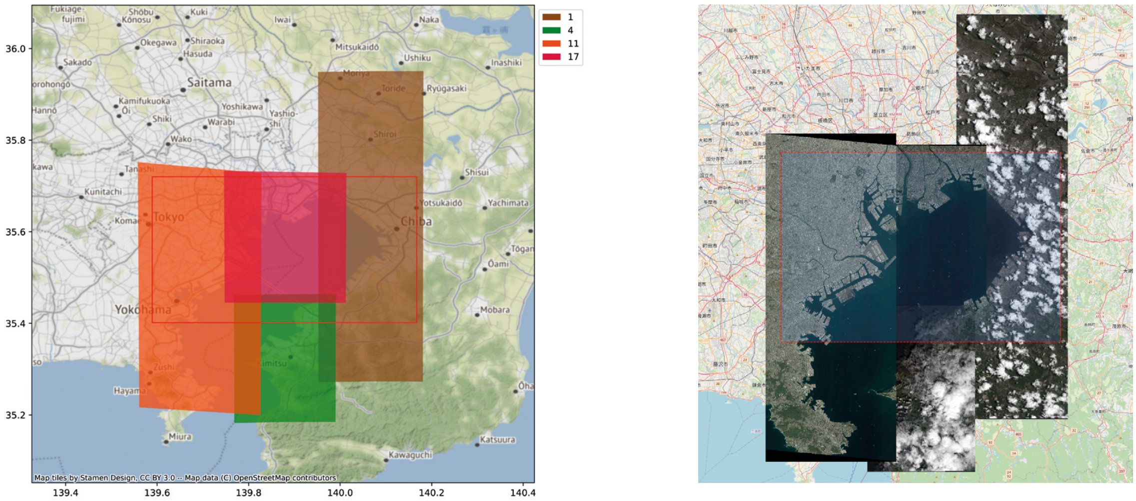

Figure 5: A simple satellite image mosaic with 4 images.

As it can be observed in Figure 5, a simple merging of the images can result in a low-quality mosaic with heterogeneous content caused by, for instance, the presence of seams or differences in the colours of the images. Creating a high-quality mosaic presents three main challenges:

- **Geometric correction of the images:** images can be distorted when they are taken from a satellite with a non-0-degree angle.
- **Colour harmonization:** images that are part of the mosaic can have different colour tones, because they were taken in different moments of the day/month/year, with different illumination for example.
- **Image stitching:** how to merge adjacent images, considering seam-line detection like roads and rivers.

3.1.3. Current research problem and related trustworthiness aspects

3.1.3.1. Research problem

Besides the above-mentioned challenges, new ones originate from the need to combine the images and the existence of a large image panel. Indeed, the number of combinations of images used to make the mosaic increases exponentially with the number of the images available, and consequently, finding the optimal combination of images to build a mosaic upon one or more criteria (total cost, cloud coverage, incidence angle, etc.) is a complex iterative task. Even trying to optimise a single parameter (like cost) is not trivial. This has been proven to be an NP-hard problem [2] meaning that for a small increase in the number of images, the time to explore all possible solutions and select the best one increases exponentially, and after a certain number of images it becomes impossible to explore all the solutions. In the rest of the document we will refer to this problem as Satellite Image Mosaic Selection (SIMS).

An example of this problem is shown in Figure 6, where 30 images are available to build a mosaic, but only 4 images are sufficient to cover the AOI, which makes the mosaic creation easier, faster and cheaper.

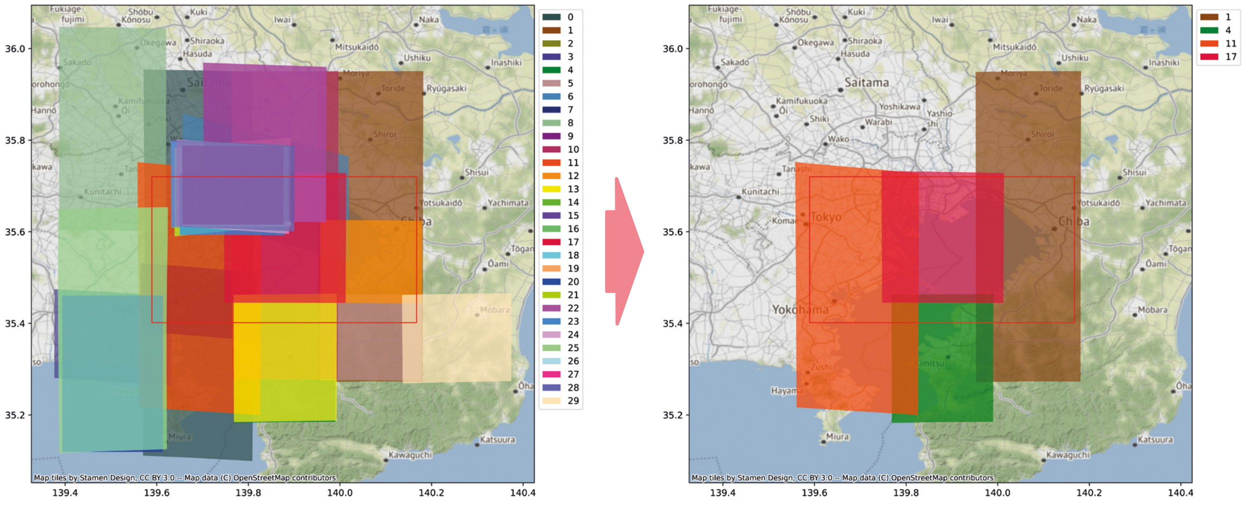

Figure 6: Image selection for mosaic creation without (30 images - left) and after optimization (4 images - right).

Any combination of images that can cover the AOI is a solution for the problem; for example the simplest solution is to select all the images from the marketplace that cover the AOI, but this solution would be the most expensive one. Recommending a reasonably good solution to the previous problem could make users prefer one Satellite Images Marketplace over another. Thus, our research focuses on the development of algorithms that allow to select a near-optimal combination of images to create a mosaic covering the given AOI and respecting users' constraints.

In this problem, the user's input consists in the selected AOI and the requirements for the images such as cloud coverage percentage, incidence angle, date of images and resolution. Once these are determined, the system should recommend a group of solutions consisting of a set of images that covers the entire AOI where each of the solutions optimises one or several criteria from user requirements. For example, in the provided solutions, one can be cheaper than the others but have more cloud coverage percentage (optimisation on price criterion), meanwhile another solution would have less cloud coverage but could be more expensive (optimisation on cloud coverage). The final choice is left to the user.

3.1.3.2. Trustworthiness considerations

Current research activities try to provide an answer to the technical side of the problem mentioned above. However, it is also crucial to address another side of the problem, which consists in gaining end-user trust and allowing the user to make the final choice with confidence. To do so, a first step would be to identify the trustworthiness characteristics involved in the process of mosaic creation that contribute to the objective of gaining user's trust. Trust in the final result relies on the trust a user can have in the input data (images), processing phase of the system and suggested output. Thus, the trustworthiness characteristics of these components are considered below.

System and output trustworthiness characteristics

The trustworthiness characteristics (see Section 1.3) directly impacting the user's trust at the level of processing system and the output are:

- **Accuracy.** The accuracy of the system is given by comparing itself against similar strategies using a common benchmark and, when possible, comparing it against the optimum solution (for large test cases it could be impossible to find the optimum). Here, the trust aspects lie in how well the benchmark was designed, how many tests were conducted and which algorithms the heuristics were compared to.
- **Integrity.** Completeness is essential. That is, if it is possible to cover the AOI with the existing images, the system should provide the necessary images to make the mosaic. The system has to guarantee that all the images in the solution can be merged. The proposed solution shall fully answer the user request with a high level of quality.
- **Robustness.** The system should maintain its level of performance for a wide range of different test cases. Verification can be done by designing a benchmark for the heuristics.
- **Transparency.** When a solution is found, the system should display the selected images (and their information) to the user and detail how the merge covers the AOI. The system should also be transparent with respect to the pricing: the system should give the total cost of the proposed solution.
- **Usability.** Depending on the final application, user requests can be different: for example, a given user may be interested in high-resolution images, or in images with low cloud coverage, or even in images with low incidence angle. The system should allow the user to set different parameters of the request in order to define the objective to be optimised (price, cloud coverage, number of images, or a combination of them). Thus, configurability is also usability.

Input data trustworthiness characteristics

In a system, the quality of the entire system depends on the quality of its components. Therefore, input data is as important as output data to reach the expected level of trustworthiness of the complete system: any lack of trust in input data will undermine the credibility of the final proposed solution. Although images can be considered as the main element of the input data, some metadata related to images are essential for their usage and processing. In the frame of SIMS, these metadata are image coordinates. Without having access to them, positioning an image on a map is impossible when creating a high quality mosaic. Other metadata – such as time, cloud coverage, incidence angle, etc. – are also useful because they help select images that satisfy users' requirements.

Images and related metadata are information provided by the satellite image provider. In addition, user requirements also have to be considered as input data, so that the output could comply with the *usability, configurability* and *integrity* trustworthiness characteristics. Indeed, comparing and matching metadata with user requirements contributes to the identification of the optimal SIMS solution.

Trustworthiness characteristics applicable to the input data are listed below. It is important to be able to compare the input data *i.e.* original images/coordinates, upon these criteria. This will support the trustworthiness of the SIMS recommendations since all the input images would be at the same level with respect to the initial user requirements.

Accuracy (data)

Accuracy of the image would depend on the image geographic coordinate error, which is given due to satellites movement, resolution of the image and projection of the image.

- **Images.** Distortions in the image can cause an incorrect representation of the ground. The direct consequence in this case is a mismatch between a pixel and its geoposition, and in the end, a proposed solution which does not fully cover the AOI.
- **Geographic coordinates.** Any lack of accuracy on this aspect can lead to the similar undesired effects as mentioned above.
- **Information to display the final mosaic on a map.** Besides the coordinates of the images, it is necessary to know the Geographic Coordinate System and Projected Coordinate Systems. The Geographic Coordinate System is a model of the surface of the Earth that allows positioning the image using the given coordinates, and Projected Coordinate Systems are used to display the image on a flat representation of that model [3]. If this information is not specified for the image, the default Geographic Coordinate System and Projected Coordinate Systems are WGS84 (World Geodetic System 1984) and UTM (Universal Transverse Mercator), respectively. Also, it can be necessary to orthorectify the image, a process that allows to eliminate the projection errors in the image due to the incidence angle.

Quality

When a user makes a query, the system should return only the images that intersect with the area of interest and meet the user criteria (cloud coverage percentage, incidence angle, date of images, resolution, etc).

- **Incidence angle.** This is the angle formed between the ground normal and the observation direction of the satellite. For most applications, it is preferable to have images with a lower incidence angle.
- **Cloud coverage.** This is one of the most important aspects of a satellite image mosaic. In a satellite image, clouds 'hide' the ground below them and make that zone of the image useless for most applications. To generate mosaics with low cloud coverage it is important to detect the clouds in the images; in this way, the algorithm can find a combination of images where cloudy regions can be replaced by non-cloudy regions. Some satellite image providers indicate where clouds are. If this information is not provided, the following information is necessary for a pre-processing step of cloud detection:
  - Sun elevation;
  - Sun azimuth;
  - Incidence angle.
- **Resolution of the image.** This is one of the most important aspects for the user. Depending on the application, users would need images with varying resolution.

Transparency

All the images should have information about their provenance, *i.e.* the satellite constellation that captured it, and the date and time of the image capture itself. Without the dates of the images the user cannot make a query to get images from a certain time range. Also, it is important to know the time of the day when the image was taken, to allow querying for a specific time of day, for example if a user is interested in images taken only in the morning.

3.1.4. Standardization in support of trustworthiness

3.1.4.1. Quality and accuracy of input data

As discussed above, accuracy of output data is dependent on the accuracy of the input data, which are composed of – but not limited to – 1) the image and 2) coordinate information. Images are, with no exception, produced by an image sensor (composed of an electrical transducer and optical elements) which converts the radiative energy of the light into digitized data to finally create the ground image. Similar to the images, coordinates are derived from satellite attitude acquired via sensors present on-board. As in any physical system, error tolerance in sensors assemblies influences its accuracy and performance, and consequently impacts image quality and accuracy. Although manufacturing techniques are constantly improved, error tolerance will always be present in the final system and will have to be compensated through assessment, evaluation and calibration.

Different standards related to satellite imagery have been developed in support of image capture quality by providing methods to calibrate sensors or to assess output data quality. In Table 2, four useful standards, with their brief scopes and their relevance to the SIMS problem, are introduced.

<table>
<tr><th>Standard title</th><th>Standardization committee</th><th>Scope extract/description</th><th>Trustworthiness characteristics affected</th></tr>
<tr><td rowspan="2">ISO 19157-1:2023

Geographic information — Data quality — Part 1: General requirements[51]</td><td>ISO/TC 211 Geographic information/ Geomatics[52]</td><td>This document establishes the principles for describing the quality of geographic data. It:
• defines a well-considered system of components for describing data quality;
• defines the process for defining additional, domain-specific components for describing data quality;
• specifies components and the content structure of data quality measures;
• describes general procedures for evaluating the quality of geographic data;
• establishes principles for reporting data quality.
[...]</td><td>Quality, Accuracy</td></tr>
<tr><td colspan="3">Relation to the research topic

This relates to the overall data of the system. This standard provides, in its Annex B, several standardized data quality measures which cover, in the case of the SIMS problem:
• Positional accuracy,
• Temporal quality.

The methods presented in this document allow the satellite provider to compute errors inherent to its global system (images acquisition and associated geoposition system). Contrary to other standard that focus on equipment specific errors, this one provides a holistic way of assessing geographic data quality based on the output geographic object.

Additionally to this error calculation, the standard presents a methodology to report data quality information to the customer. In the context of a marketplace this information is relevant and allows interoperability between the different image providers.</td></tr>
</table>

51 https://www.iso.org/standard/78900.html

52 https://www.iso.org/committee/54904.html

<table>
<tr>
<td rowspan="2">ISO/TS 19159-1:2014

Geographic information — Calibration and validation of remote sensing imagery sensors and data — Part 1: Optical sensors[53]</td>
<td>ISO/TC 211 Geographic information/Geomatics</td>
<td>ISO/TS 19159-1:2014 defines the calibration and validation of airborne and spaceborne remote sensing imagery sensors. The term "calibration" refers to geometry, radiometry, and spectral, and includes the instrument calibration in a laboratory as well as in situ calibration methods. The validation methods address validation of the calibration information.</td>
<td>Quality, Accuracy</td>
</tr>
<tr>
<td colspan="3">Relation to the research topic

This has relevance mainly to the image itself. The performance of an optical sensor can be compromised due to several risks during its manufacturing possibly leading to :
• incorrect focus point,
• geometrical deformation,
• incorrect color representation of the acquired image.

The document presents the methodology to be followed in order to calibrate and validate optical sensors, and the way to present calibration data of the sensor. This technical specification, in complement of ISO 19157 and ISO 19130-1, allows to have a Unified Modeling Language (UML) class containing all calibration information of optical sensors.</td>
</tr>
<tr>
<td rowspan="2">ISO 19130-1:2018

Geographic information — Imagery sensor models for geopositioning — Part 1: Fundamentals[54]</td>
<td>ISO/TC 211 Geographic information/Geomatics</td>
<td>This document identifies the information required to determine the relationship between the position of a remotely sensed pixel in image coordinates and its geoposition. It supports exploitation of remotely sensed images. It defines the metadata to be distributed with the image to enable user determination of geographic position from the observations. [...]</td>
<td>Accuracy</td>
</tr>
<tr>
<td colspan="3">Relation to the research topic

Coordinate information is vital. This standard is extremely important to guarantee the accuracy of the input data in the SIMS problem, especially from the geopositioning aspect. Moreover, as a part of the geopositioning task, sensor correction methods are described, by taking into account all distortion that may occur due to sensor assembly and environmental conditions.

A concrete example of how errors in the geographic coordinates of an image can affect the mosaic is depicted in Figure 7.

Another consequence could be not selecting the image for the mosaic at all, as the shift could be too big and the algorithm would thus choose other images as better covering the area. In this case, the produced mosaic may accurately represent the area, but it may not be the best possible solution.

The algorithm to solve the SIMS problem assumes that all the images have correct geographic coordinates. Automatically verifying that all the images have the correct coordinates can be very complicated. Thus, one way to avoid this type of error is for satellite companies to follow this standard.</td>
</tr>
</table>

53 https://www.iso.org/standard/60080.html

54 https://www.iso.org/standard/66847.html

ISO 19116:2019 Geographic information — Positioning services[55]	ISO/TC 211 Geographic information/Geomatics	This document specifies the data structure and content of an interface that permits communication between position-providing device(s) and position-using device(s) enabling the position-using device(s) to obtain and unambiguously interpret position information and determine, based on a measure of the degree of reliability, whether the resulting position information meets the requirements of the intended use. A standardized interface for positioning allows the integration of reliable position information obtained from non-specific positioning technologies and is useful in various location-focused information applications, such as surveying, navigation, intelligent transportation systems (ITS), and location-based services (LBS).	Accuracy
	Relation to the research topic This relates to coordinates. This standard provides a description of positioning information which can be shared between different entities. The information shared via this protocol allows to reach confidence in the satellite position and consequently in the geopositioning information of the resulting images		
ISO/AWI 20550 Space systems — Pointing management for optical Earth observation[56]	ISO/TC 20/SC 14 Space systems and operations[57]	This document specifies pointing management to control which direction the optical remote sensor onboard the spacecraft points to.	Accuracy
	Relation to the research topic This is more a document in relation with the satellite's sensors. Currently under development, this standard will help to improve the quality of the satellite image acquisition.		

Table 2: Standards, and standards under development, related to the accuracy and the quality of the input data.

55 https://www.iso.org/standard/70882.html

56 https://www.iso.org/standard/86312.html

57 https://www.iso.org/committee/46614.html

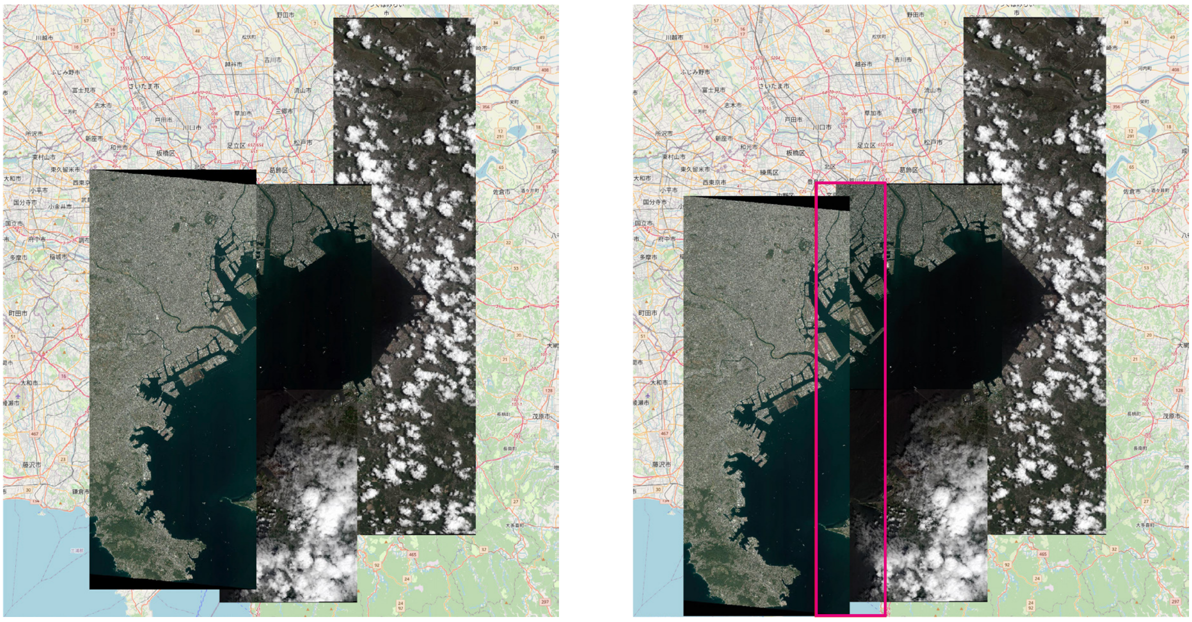

Figure 7: An example of how errors in geographic coordinates of satellite images can affect the mosaic terrain representation.

3.1.4.2. Image pre-processing and metadata

Beyond the satellite images being themselves correct, they afterwards need to be pre-processed by the satellite providers or marketplaces in order to harmonize them and improve their quality. Several pre-processing tasks are needed, such as radiometric correction or grey level stretching, but in the context of the SIMS problem, orthorectification and cloud detection are the main ones.

Orthorectification

Orthorectification impacts the visual quality of the final mosaic. It consists in eliminating the distortions that are due to the fact that the image was taken with a high view angle. As a result, the images are corrected to look like zero-degree-view-angle images. This process is quite complicated and it is recommended to work with images where orthorectification was already done by the image provider instead of doing it oneself.

Table 3 lists useful standards for the orthorectification pre-processing task and specifies their relevance to the SIMS problem.

Standard title	Standardization committee	Scope extract/description	Trustworthiness characteristics affected
ISO 19130-1:2018 Geographic information — Imagery sensor models for geopositioning — Part 1: Fundamentals[58]	ISO/TC 211 Geographic information/ Geomatics[59]	This document identifies the information required to determine the relationship between the position of a remotely sensed pixel in image coordinates and its geoposition. It supports exploitation of remotely sensed images. It defines the metadata to be distributed with the image to enable user determination of geographic position from the observations. [...]	Accuracy
	Relation to the research topic This relates to the pre-processing for orthorectification. Already mentioned in the input data chapter, this standard covers the distortion correction related to the optical sensor and environmental distortion but can be extrapolated to orthorectification also. Knowing the change of coordinates system and the definition of model allows to create the link between pixel and geopositioning coordinates and thus remove the distortions related to the incidence angle. To reach this target, several models are presented in order to cover all the different types of implementation possibilities: (1) the Physical Sensor Model (PSM) that allows to reach high precision but needs high computational power, (2) the True Replacement Model and (3) the Correspondance Model which are based on PSM fit or on Ground Control Points, respectively.		
ISO/TS 19159-1:2014 Geographic information — Calibration and validation of remote sensing imagery sensors and data — Part 1: Optical sensors[60]	ISO/TC 211 Geographic information/Geomatics	ISO/TS 19159-1:2014 defines the calibration and validation of airborne and spaceborne remote sensing imagery sensors. The term "calibration" refers to geometry, radiometry, and spectral, and includes the instrument calibration in a laboratory as well as *in situ* calibration methods. The validation methods address validation of the calibration information.	Accuracy
	Relation to the research topic This is also a document for the pre-processing of orthorectification. Already mentioned in the previous section, Annex C of this document presents different self-calibration models which allow geometrical corrections of optical sensor. As the geometrical distortions caused by the acquisition angle can be compared to optical sensor distortions, information presented in this document, in addition of ISO 19130-1, would allow to better accomplish the orthorectification task.		

58 https://www.iso.org/standard/66847.html

59 https://www.iso.org/committee/54904.html

60 https://www.iso.org/standard/60080.html

EN 17030:2018 Space - Earth observation – Image processing levels[61]	CEN/CLC/JTC 5 Space[62]	This European Standard specifies the definition of the different processing steps (levels) of images coming from Earth observation systems observing the surface of the Earth regarding the different sensor sources of the origin data. It applies at least to image products generated from the following types of sensors: • electro-optical (including infrared and hyper-spectral); • SAR (Synthetic Aperture Radar). The standard allows to identify the information depth and the used auxiliary data/information. Furthermore it allows the comprehension of image data from different sources and gives hints about the information compatibility.	Quality
	Relation to the research topic This standard provides a classification of the different images according to processing steps. It covers pre-processing in general. This classification may support the transparency characteristic through the forwarding of this classification information of mosaic-selected images to the user.		

Table 3: Standards related to the preprocessing steps of the input data.

Cloud detection

Cloud detection consists in the identification of the clouds' location in the images. In many cases the satellite image providers add an extra layer to the image, or a mask, indicating whether a pixel forms part of a cloud, a haze or a cloud shadow.

The algorithms designed to solve the SIMS problem, besides relying on the quality and accuracy of the input data, heavily depend on the correct implementation of this pre-processing step. Indeed, any incorrect detection of clouds can impact the quality of the proposed solution in two ways:

1. Percentage of clouds detected is lower than reality. In this context, the solution proposed could not fully answer the user's requirement with regards to cloud coverage criteria.
2. Percentage of clouds detected is higher than reality. The algorithm, in such a case, could create a mosaic with extra images or with images with lower cloud coverage, resulting in unnecessary effort.

In both situations, the quality of the proposed mosaic is impacted by incorrect detection, causing in the first case an alteration of user experience by providing a solution which does not fulfil the required criteria (cloud coverage percentage), and in the second case a violation of the optimal solution constraint of SIMS (cost versus available images). Practically, a SIMS algorithm needs to know where the clouds are to select a combination that can eliminate most of them in order to fully tackle both this quality challenge and user expectations.

Currently, recognized standardization organizations have not yet developed a standard for cloud detection methods. Every image provider and marketplace uses its own algorithms. However, in some cases, a confidence level of the classification and the methods used for cloud detection are given.

61 https://standards.cencenelec.eu/dyn/www/f?p=CEN:110:0::::FSP_PROJECT,FSP_ORG_ID:40531,887985&cs=17BA61C34E857A28DFEDF75352FE16303

62 https://standards.cencenelec.eu/dyn/www/f?p=205:7:0::::FSP_ORG_ID:887985&cs=17D471F6F920904967AFC18C2BDA2F89F

In the System and output trustworthiness characteristics section, we emphasized the impact of metadata on the identified trustworthiness characteristics of output data. The role played by them, with respect to the pre-processing tasks, is similar: any lack of metadata can make it impossible to create an image mosaic with high level of quality. To properly execute these tasks different types of information should be provided as metadata. For readability, only information needed for cloud coverage pre-processing tasks is outlined in Table 4.

Pre-processing task	Information needed
Cloud coverage detection	Mask indicating which pixels belong to a cloud or to a shadow of a cloud
	In case a mask for cloud detection is not provided then the following fields are necessary: • Incidence angle • Sun azimuth • Sun elevation • Cloud coverage. This field indicates the total area of the clouds in the image, it should be similar to the area detected using the previous three fields

Table 4: Additional information needed for cloud coverage detection task

In every case, metadata of satellite images are associated with the visual content. However, no naming convention for the metadata is currently set and each marketplace has its own metadata schema, which in many cases is very basic - containing items such as date and resolution - and does not allow for a complete registration of metadata from the image providers. The metadata that does not fit the basic schema of a marketplace but is provided by the satellite mission is stored in a single special field. For example, in the UP42[63] marketplace, that field is called *providerProperties* and simply contains image provider information without any processing. At the same time, satellite companies have a more robust metadata schema, although not all of them follow a standard. For example, SkySat[64] follows the application schema defined in the *Open Geospatial Consortium (OGC) Best Practices document for Optical Earth Observation products version 0.9.3* [4], meanwhile SPOT and Pléiades[65] follow the standard introduced for the SPOT 5 launch in 2002, DIMAP[66].

The diversity of sources of satellite imagery and the metadata schema used by each of them can create inconsistency in the metadata info: the metadata fields could have different naming conventions and the values could be in different units of measurement, causing interoperability problems. We can see a concrete example of this fact in Table 5.

ISO/TC 211 *Geographic information/Geomatics* is the technical committee in ISO handling all activities related to digital geographic information. This committee published a set of standards (the ISO 19115 series - Geographic information — Metadata) which defines the metadata elements, their properties, and the relationships between elements, and establishes a common set of metadata terminology, definitions and extension procedures which may give uniformity in the description of metadata. As of the time of writing of this document, three standards have been published (not including amendments), and a fourth is under development:

63 https://up42.com/
64 https://earth.esa.int/eogateway/missions/skysat#instruments-section
65 https://www.intelligence-airbusds.com/imagery/constellation/
66 https://www.intelligence-airbusds.com/dimap/spec/documentation/refdoc.htm

- ISO 19115-1:2014 Geographic information — Metadata — Part 1: Fundamentals[67]
- ISO 19115-2:2019 Geographic information — Metadata — Part 2: Extensions for acquisition and processing[68]
- ISO 19115-3:2023 Geographic information — Metadata — Part 3: XML schema implementation for fundamental concepts[69]
- ISO/AWI TR 19115-4 Geographic information – Metadata — Part 4: JSON schema implementation of metadata fundamentals in ISO Projects[70].

In Table 5, a comparison is made between the naming convention proposed by the ISO 19115 standards series, the marketplace UP42 and the satellite missions SkySat and Pléiades for the necessary fields for cloud coverage pre-processing. We can notice several differences in the metadata fields:

- In UP42 the metadata scheme only has the geographic coordinates, the date and time, the resolution and cloud coverage. Fields like incidence angle have to be accessed through the metadata field that contains the rest of the metadata field coming from the provider.
- Geographic coordinates and cloud coverage have the same name in UP42 and Pléiades, but have different names in SkySat.
- Skysat has a metadata field to indicate the method used for cloud detection.

Users should be aware of the differences mentioned above, especially if they are accessing the data through an API, in which case they have to implement a translator to assign a unique name and unit of measure for fields that are equivalent. For the naming convention of the translator it could be a good idea to use the standards ISO 19115-2 Annex C and ISO/TS 19115-3. In the future, marketplaces could implement these standards to facilitate users' access to, and querying of, metadata.

Metadata	ISO 19115 name	Marketplace	Satellite mission	
		UP42	**SkySat**	**Pléiades**
Geographic coordinates	/	geometry	posList	geometry
Date and time of the image	Time	acquisitionDate	acquisitionDate	acquisitionDate
Resolution of the image	groundResolution	resolution	resolution	resolution
Incidence angle	/	In the provider field	incidenceAngle	incidenceAngle
Cloud coverage	cloudCoverPercentage	cloudCoverage	cloudCoverPercentage	cloudCover
Method of cloud cover determination	/	In the provider field	cloudCoverPercentage QuotationMode	/
Sun elevation	illuminationElevationAngle	In the provider field	illuminationElevationAngle	illuminationElevationAngle
Sun position	illuminationAzimuthAngle	In the provider field	illuminationAzimuthAngle	illuminationAzimuthAngle

Table 5: Sample of the naming conventions for the metadata fields necessary for the satellite image mosaic selection problem for one marketplace and two satellite missions.

67 https://www.iso.org/standard/53798.html?browse=tc

68 https://www.iso.org/standard/67039.html?browse=tc

69 https://www.iso.org/standard/80874.html

70 https://www.iso.org/standard/86968.html?browse=tc

3.1.4.3. Image selection and mosaic creation

Once all the images satisfy the quality requirements, the final step is to select the relevant images and to create a mosaic. As was explained in the previous section, the selection of the images is an NP-hard problem. Thus, it may be impossible to select the best combination of images. However, it is possible to define a heuristic that could be verified on a smaller amount of images and that would allow the selection of a reasonably good combination.

So far, there are no standards that advise how to measure the quality of a heuristic for an NP-hard problem. But it is worth noting that an International standardization committee, ISO/TC 69 *Applications of statistical methods*[71], works on various aspects of the usage of statistics including generation, collection (planning and design), analysis, presentation and interpretation of data. One of its sub-committees, SC 8 *Application of statistical and related methodology for new technology and product development*[72] works on standards related to the verification of the quality of the new digitalized products and services. In this context, the algorithm for proposing an image mosaic could be considered as a new digitalized service. Nevertheless, the proposed standards concern mostly the verification of new products and services when they reach the mass audience and thus are not directly applicable to the current research problem.

3.1.5. Use case conclusion

In this use case we presented what satellite image mosaics are and why they are important. We briefly touched upon the technical challenges of building a mosaic and focused on the new combinatorial challenge of selecting the base input images, which has been clearly identified as an NP-hard problem.

However, efficiently tackling the challenge of providing a satellite image mosaic is not limited to good design and implementation of technology; trustworthiness aspects have to be considered as well. With the purpose of addressing this issue, we identified the main trustworthiness characteristics of the images selection challenge from the point of view of the system and output data, and input data.

We have identified several standards that could be followed by satellite missions to generate images with good accuracy and quality, specifically to guarantee the image resolution and minimize the error in the geographic coordinates. Errors in the geographic coordinates of images can seriously affect the validity of the solution, as the mosaic could wrongly represent the area of interest. Furthermore, the quality of the solution can deteriorate when the best image covering a region in the area of interest is not selected because of incorrect coordinates and another image, of inferior quality, is selected instead.

Of the same importance as the successful capture of satellite images following the appropriate standards, is the accurate pre-processing of the images. Within the context of the satellite image mosaic selection problem, two main pre-processing steps stand out: orthorectification and cloud detection. Orthorectification plays a vital role in enhancing the visual quality of the images, eliminating the distortions in the images acquired with a view angle different from directly above. Similarly to the orthorectification tasks, cloud detection is fundamental to fulfil quality criteria but also to satisfy user requirements. Unfortunately, no standard providing harmonized methods to do so is currently available.

Thus, a fundamental requirement would be to implement a robust metadata scheme that guarantees the right exploitation and interoperability of the images. As the number of sources and generated satellite imagery is rapidly increasing, it is extremely important to try to unify all the metadata schemes in usage, and technical standardization can be used to start achieving this. We have demonstrated that different satellite image providers use different standards resulting in different naming conventions, and the efforts of the marketplaces

71 https://www.iso.org/committee/49742.html

72 https://www.iso.org/committee/585031.html

to overcome this issue seems insufficient, as their metadata scheme is too simple and cannot cover all the fields present in the metadata scheme of the providers. This leads to registration of most of the metadata under a single field and interpretation is left to the user. Such a scenario reduces interoperability and the efficiency of mosaic creation. To improve the situation, a possible option is to implement a more robust metadata scheme following the standards ISO 19115-2 Annex C and ISO 19115-3. In this way the users can easily compare and work with data from different providers.

To summarise, there exist standards that can contribute to the trustworthiness of satellite image mosaic creation at different levels. However, an overarching effort of satellite image providers and marketplaces is needed to implement them and render them really useful. Moreover, some aspects of mosaic creation, such as an algorithm for image selection, remain purely in the realm of research and no standards support is currently available. In this frame, the case can be made that an integration of current research results in future standards to support this would be welcome.

3.2. Building Information Modelling

3.2.1. Automation in construction and Building Information Modelling

Prior to the fourth industrial revolution, construction optimization was constrained by existing manual technology. Construction project management heavily relied on human expertise and knowledge, and optimization was typically achieved by trial and error. The increased adoption of automation, artificial intelligence, Internet of Things (IoT), and other technological breakthroughs through this fourth industrial revolution are progressively changing the construction sector into a more digitized industry. In particular, this revolution has brought forth the concept of Building Information Modelling, or BIM [5].

3.2.1.1. Building Information Modelling

BIM is a refined digital depiction of a building's physical and functional attributes, possibly across the building's entire lifecycle, from its early design phase to its construction, renovation, and finally decommissioning or demolition [6]. The holistic potential of BIM is depicted in Figure 8, where an emphasis is placed on the design phase which is where this use case is primarily situated.

BIM can play a critical role in construction optimization by providing rich building information, and after the fourth industrial revolution, BIM models have become more data-driven, collaborative, and predictive. BIM techniques increase efficiency by minimizing the time-consuming and error-prone manual data entry that used to be.

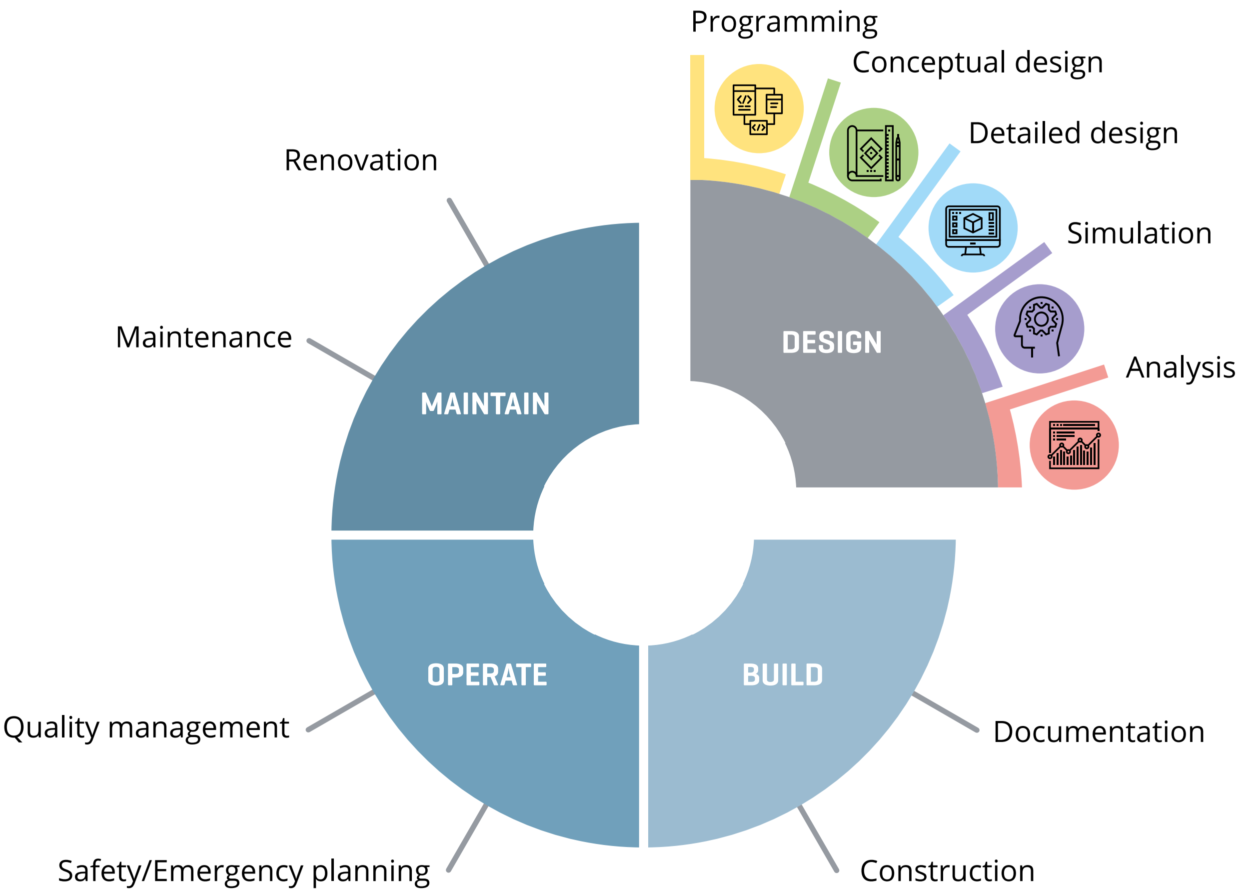

Figure 8: Role of BIM in the building workflow

Some examples of technical aspects of a construction project that can be addressed more effectively using BIM are listed below. These include both aspects related to the building itself and aspects related to management of the construction project:

- Forecasting and optimizing the final building's energy consumption during operation;
- Predicting and optimizing daylight usage;
- Optimizing indoor air quality;
- Optimizing thermal conditions within a building to ensure that occupants are comfortable;
- Better pre-determining certain aesthetic aspects such as view enhancement to provide more access to views of the outdoors;
- Optimization and forecasting for the construction work itself, for instance predicting the time required to complete the project and deliver the building;
- Selecting adequate building materials that are environmentally sustainable, healthy, and durable, and minimize waste and pollution during construction and operation.

3.2.1.2. The relation between BIM and other modern ICT tools

To create dynamic and predictive simulations and facilitate decision-making, BIM may be coupled with various modern technologies, in particular related to Artificial Intelligence (AI). For instance, multi-objective optimization algorithms are logical candidates to use in order to find system configurations that take multiple dimensions into account, so as to ultimately select one (or more) such configurations that are satisfactory in each individual dimension. Multi-objective optimization is itself also in relation to other techniques that have been used in research or real-world applications, like genetic algorithms, particle swarm optimization, ant colony optimization, and simulated annealing [7]. Classic approaches which are widely used - artificial neural networks, decision trees, and support vector machines, among other machine learning approaches - have been combined with optimization techniques to improve building design and construction. Machine learning is able to forecast how various design tactics will function by examining previous data on building performance and determining the best possible solutions. The general interaction between AI and BIM is depicted in Figure 9.

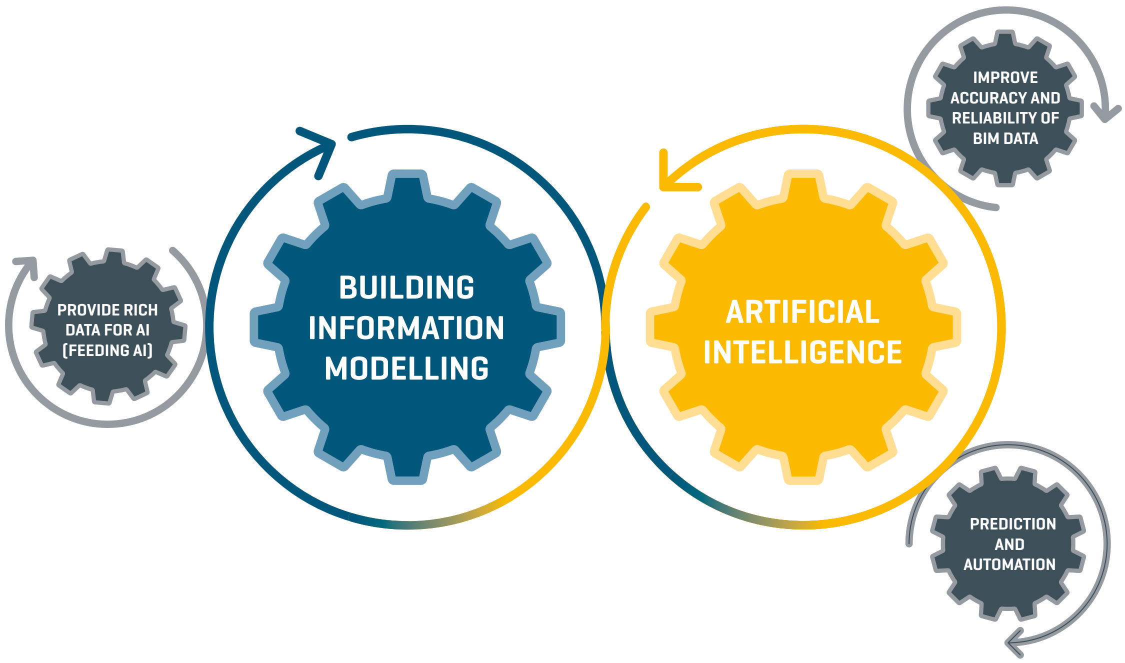

Figure 9: Interactions between BIM and AI

3.2.1.3. Trustworthiness issues in BIM as it stands today

Construction is a sector in which mistakes can have a very wide range of consequences. Some mistakes – the misalignment of floor tiles, or the usage of an incorrect color for wall paint – can be mild inconveniences at worst, while others – a design error affecting structural integrity – go as far as placing human life at risk.

Since BIM is a process that 1) involves the creation and management of a full digital representation of physical and functional characteristics of a construction project and the final building, and 2) may even contain automated decision processes through the underlying usage of AI, it is clear that the technology has inherent trustworthiness dimensions given the breadth of risk. Below, we see how these may relate to some of the trustworthiness characteristics from Section 1.3.

- **Accuracy.** The employment of digital tools raises the question of how well, or how accurately, they reflect physical reality, that is, how one can be sure that a particular configuration chosen through simulation actually yields the same results when deployed concretely.
- **Accountability.** The use of AI, which in many cases behaves as a black box, makes it difficult to justify how a particular configuration is chosen. Yet, in the construction sector – as in many other sectors that AI is proposed to be deployed in – transparency is important in particular when considering accountability in cases where human well-being and health may be placed at risk.
- **Quality.** BIM models require a vast amount of data of high quality, therefore the accuracy, completeness, and correctness of the data used to build the BIM model must be guaranteed. This can be difficult, as the data might come from several sources and not be reliable.
- **Transparency.** Data and models need to be routinely evaluated and validated by pertinent stakeholders to regularly ensure that they are correct and up to date.
- **Usability.** BIM models frequently need to be distributed among several stakeholders and software systems. Nevertheless, data may not be completely interoperable across systems, which could lead to data loss, inaccuracies, or corruption.

3.2.2. Multi-objective optimization of energy consumption, daylight usage and cost-control

Among the many challenges invoked, the research described below concerns three of them in particular. It has the ambition of finding a way to optimize them simultaneously, for a given construction project, and to do this through BIM. These challenges are 1) controlling the cost of the construction project itself, 2) managing the energy efficiency of the finished product once in operation, and 3) finding an optimal usage of daylight. We first describe these challenges in more detail, and then see how they are considered in the current activities.

3.2.2.1. Construction project aspects addressed through BIM in the research work

Cost efficiency of the construction project

In order to help construction professionals make better decisions and lower the possibility of cost overruns, machine learning algorithms are used to evaluate BIM data and provide predictions regarding project schedules, cost, resource allocation, and energy consumption. Thus, they can do cost analyses of several design possibilities and choose the most affordable one that satisfies the desired requirements.

Energy efficiency

To maximize energy efficiency, BIM can be used to simulate building performance, discover patterns in energy usage, and test various design solutions. The performance of building systems, including lighting, shading, heating, ventilation, air conditioning, etc. may be assessed through a model prior to their deployment, in particular to predict the overall energy consumption as a function of their configuration. Of special interest to us is the possibility to integrate the amount of heat a building will lose or acquire through its doors and windows (more precisely, its glazed external areas). Within a BIM system, this is done by assigning thermal characteristics values to windows, curtain walls, and facades based on how much light and heat they transfer. These values are ideally derived from actual testing on produced samples of diverse types of glass paired with various framing methods.

The total energy the building will be presumed to consume can then be estimated through calculation during the building's conception and construction periods by adding to the system further information such as schedules, manufacturer material information, and rules about the exact positioning of structural components. For windows for instance, attributes that are taken into account are addition or removal of a window, orientation, window location, window size, insulation, and material (e.g. glass) composition. This estimation is almost instantaneous whenever these parameters are updated. As a result, the design process might start off being considerably faster and more accurate. Note that in principle the same is true for other aspects, such as water usage via toiletries, electricity via lighting/equipment, etc.

Daylight-responsiveness

Natural light is another important parameter. Daylight provides better comfort (visually and psychologically) and in general ought to be favoured over artificial lighting. (However, as seen above, it can also affect other parameters such as energy efficiency.) When daylighting features are modelled in BIM systems, it is possible to determine how much natural light is available at any given time of day and on any given day of the year. By calculating averages, one can then estimate how much artificial lighting is actually required in which specific locations. This means that artificial lighting and required air conditioning can be adjusted to the lowest level possible while still maintaining a comfortable environment within the building. Advantages of an effective daylighting system include less energy usage, lower construction costs, and a more human-friendly environment.

3.2.2.2. BIM-based multi-objective optimization

The expected outcome of the research work is a semi-optimal[73] solution for the window design in a building that optimizes construction cost and energy consumption while maximizing daylighting. This solution will be provided through an optimization framework that considers various decision variables such as the building's orientation, the number and size of windows, and the materials used for construction.

To describe the project's work and make it easier to link it to standardization and trustworthiness, we describe it in terms of the BIM system's input, the system itself, and its output.

Input

Input data and information

Construction standards provide a reliable foundation for the input data of the model, which is essential for ensuring the accuracy of the optimization results. The use of systematic approaches like these enables the generation of consistent and reliable data that can be used for various building projects. See, e.g. the examples provided in Table 6.

<table>
<tr><th>Standard title</th><th>Standardization committee</th><th>Scope extract/description</th><th>Trustworthiness characteristics affected</th></tr>
<tr><td rowspan="2">ISO 19650-1:2018
Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) — Information management using building information modelling — Part 1: Concepts and principles[74]</td><td>ISO/TC 59/SC 13
Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) [75]</td><td>This document outlines the concepts and principles for information management at a stage of maturity described as "building information modelling (BIM) according to the ISO 19650 series".
This document provides recommendations for a framework to manage information including exchanging, recording, versioning and organizing for all actors.
This document is applicable to the whole life cycle of any built asset, including strategic planning, initial design, engineering, development, documentation and construction, day-to-day operation, maintenance, refurbishment, repair and end-of-life.
[...]</td><td>Quality, Accuracy</td></tr>
<tr><td colspan="3">Relation to the research topic
The ISO 19650 series in general (composed of 5 parts) is on good practices for information management across all stakeholders in a construction project through BIM. It warrants a need for interoperability and adequate cooperation between these stakeholders and the underlying systems they use. Input data following such principles ultimately benefit the overall system. The BIM data and model could be better optimized using these principles</td></tr>
</table>

73 Semi-optimal solutions are not *à priori* absolutely optimal.

74 https://www.iso.org/standard/68078.html

75 https://www.iso.org/committee/49180.html

ISO 23386:2020 Building information modelling and other digital processes used in construction — Methodology to describe, author and maintain properties in interconnected data dictionaries[76]	ISO/TC 59/SC 13 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)	This document establishes the rules for defining properties used in construction and a methodology for authoring and maintaining them, for a confident and seamless digital share among stakeholders following a BIM process. [...]	Quality, Usability, Transparency
	Relation to the research topic Interoperable and commonly accepted data formats are necessary in order to be able to optimize multiple dimensions, in particular daylight optimization, energy performance, and cost calculation, and keep the methods transparent for stakeholders		
ISO 16739-1:2018 Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema[77]	ISO/TC 59/SC 13 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)	The Industry Foundation Classes, IFC, are an open international standard for Building Information Model (BIM) data that are exchanged and shared among software applications used by the various participants in the construction or facility management industry sector. The standard includes definitions that cover data required for buildings over their life cycle. [...]The Industry Foundation Classes specify a data schema and an exchange file format structure. [...]	Quality, Usability, Transparency
	Relation to the research topic Interoperable and commonly accepted data formats are necessary in order to be able to optimize multiple dimensions, in particular daylight optimization, energy performance, and cost calculation, and keep the methods transparent for stakeholders.		
ISO 10916:2014 Calculation of the impact of daylight utilization on the net and final energy demand for lighting[78]	ISO/TC 274 Light and lighting[79]	ISO 10916:2014 defines the calculation methodology for determining the monthly and annual amount of usable daylight penetrating non-residential buildings through vertical facades and rooflights and the impact thereof on the energy demand for electric lighting. It can be used for existing buildings and the design of new and renovated buildings. [...]	Accuracy
	Relation to the research topic Standardized calculation methodologies for lighting estimations and the resulting electrical demand for artificial lighting can be integrated to the formulae to optimize when weighing natural light against energy consumption in BIM models. Thus, this serves the dual purpose of daylight optimization and energy performance.		

76 https://www.iso.org/standard/75401.html
77 https://www.iso.org/standard/70303.html
78 https://www.iso.org/standard/46394.html
79 https://www.iso.org/committee/4418564.html

ISO 10077-1:2017 Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Part 1: General[80]	ISO/TC 163/SC 2 Calculation methods[81]	ISO 10077-1:2017 specifies methods for the calculation of the thermal transmittance of windows and pedestrian doors consisting of glazed and/or opaque panels fitted in a frame, with and without shutters.	Accuracy
	Relation to the research topic Also related to the energy optimization of daylight usage is the effect of natural lighting generating heat through translucent and transparent material. Standardized formulae to estimate this can be used in BIM models.		

Table 6: Standards potentially useful as input to the system

80 https://www.iso.org/standard/67090.html

81 https://www.iso.org/committee/53512.html

The incorporation of real-world data collected from the industry that accounts for environmental parameters can also enhance the model's accuracy and effectiveness. Such data can include information on energy consumption patterns, environmental conditions, and occupant behaviour. By integrating such data, the model can produce more realistic results and consider the real-world factors that affect building performance. It also has a real-world baseline with which to compare its predictions to. This approach can lead to more sustainable and efficient building designs and can also help to ensure that the resulting buildings are more compatible with their surrounding environments. See Table 7 for examples of standards that can aid in acquiring such data.

<table>
<tr><th>Standard title</th><th>Standardization committee</th><th>Scope extract/description</th><th>Trustworthiness characteristics affected</th></tr>
<tr><td rowspan="2">ISO 52000-1:2017

Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures[82]</td><td>ISO/TC 163

Thermal performance and energy use in the built environment[83]</td><td>ISO 52000-1:2017 establishes a systematic, comprehensive and modular structure for assessing the energy performance of new and existing buildings (EPB) in a holistic way.

It is applicable to the assessment of overall energy use of a building, by measurement or calculation, and the calculation of energy performance in terms of primary energy or other energy-related metrics. It takes into account the specific possibilities and limitations for the different applications, such as building design, new buildings 'as built', and existing buildings in the use phase as well as renovation.</td><td>Reliability, Accuracy, Accountability</td></tr>
<tr><td colspan="3">Relation to the research topic

Importance is attached to making realistic predictions on energy consumption in a given model, or it will have only limited use. Thus, having a standardized methodology that can estimate energy consumption after the fact in order to have a realistic baseline for comparison with the model predictions is extremely useful, in particular to keep the underlying system – which may be AI-supported – accountable for its predictions.</td></tr>
<tr><td rowspan="2">ISO/CIE 20086:2019

Light and lighting — Energy performance of lighting in buildings[84]</td><td>ISO/TC 274 Light and lighting</td><td>This document specifies the methodology for evaluating the energy performance of lighting systems for providing general illumination inside non-residential buildings and for calculating or measuring the amount of energy required or used for lighting inside buildings. [...]</td><td>Reliability, Accuracy, Accountability</td></tr>
<tr><td colspan="3">Relation to the research topic

Similar considerations as above in terms of having baseline realistic energy performance and lighting performance against which to hold the BIM modeling accountable.</td></tr>
</table>

82 https://www.iso.org/standard/65601.html

83 https://www.iso.org/committee/53476.html

84 https://www.iso.org/standard/67002.html

ISO 15469:2004 Spatial distribution of daylight — CIE standard general sky[85]	CIE International Commission on Illumination[86]	ISO 15469:2004 defines a set of outdoor daylight conditions linking sunlight and skylight for theoretical and practical purposes.	Accuracy
	Relation to the research topic Baseline reference values for general sky illumination are critical to agree on for them to be of use in multi-stakeholder BIM systems that makes predictions on usable daylight on a given time or day. This is an important component for daylight optimization.		

Table 7: Standards useful for real-world data collection

Input software

The software used in this research for generating the model, Autodesk Revit[87], is widely used in the architecture, engineering, and construction industry. The use of Dynamo[88], a visual programming add-in for Revit, allows for the automation of repetitive tasks and facilitates the creation of complex algorithms for optimization purposes. Figure 10 shows a building as modelled in Revit, taking into account parameters such as orientation, time of day, window sizes and placements, among others. For BIM, the chain of trustworthiness also goes through the underlying software supporting and implementing the modelling itself. Thus, it is worth mentioning (although this is not part of the research problem) that assurance on the quality of this software is important.

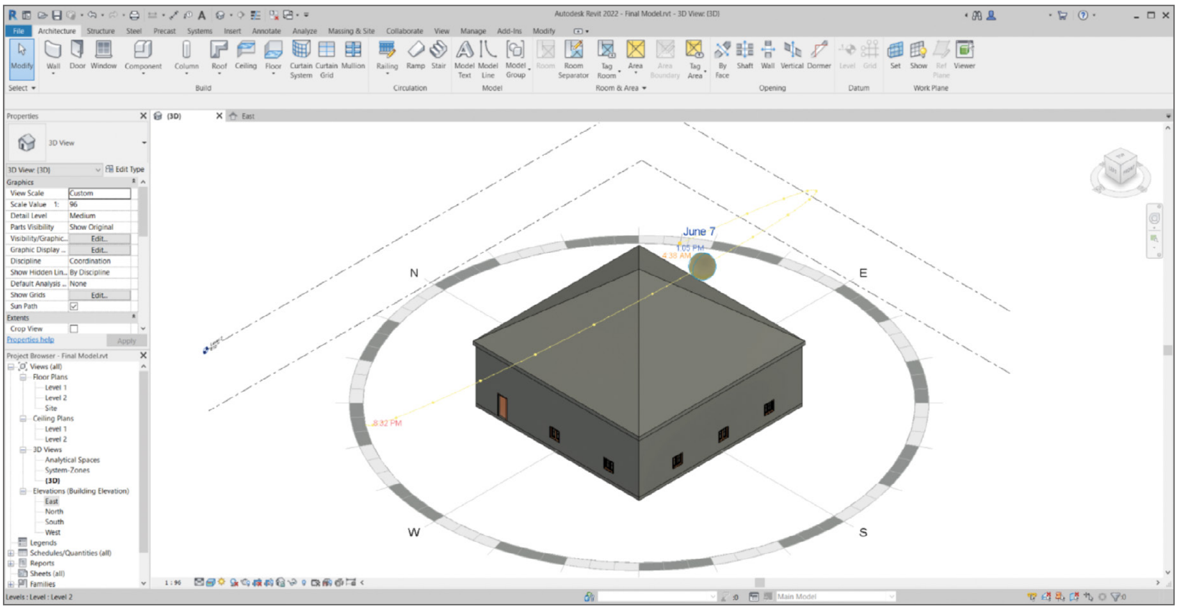

Figure 10: A building modelled in Revit

Many organizations and regulatory bodies advocate for standardized software solutions to promote compatibility, collaboration, and consistent quality across projects. This emphasis on standardization facilitates seamless data exchange, promotes interoperability among different stakeholders, and enhances overall efficiency in the design and construction process. With industry-wide adoption and a commitment to quality assurance, these software tools contribute to the advancement of the industry as a whole. Table 8 shows a few standards that cover this area.

85 https://www.iso.org/standard/38608.html

86 https://www.iso.org/committee/55238.html

87 https://www.autodesk.com/products/revit/overview?term=1-YEAR&tab=subscription&plc=RVT

88 https://www.autodesk.com/products/dynamo-studio/overview

Standard title	Standardization committee	Scope extract/description	Trustworthiness characteristics affected
ISO/IEC 33063:2015 Information technology — Process assessment — Process assessment model for software testing [89]	ISO/IEC JTC 1/SC 7 Software and systems engineering [90]	ISO/IEC 33063:2015 [...] provides guidance, by example, on the definition, selection, and use of assessment indicators. A process assessment model comprises a set of indicators of process performance and process capability. The indicators are used as a basis for collecting the objective evidence that enables an assessor to assign ratings [...].	Accuracy, Quality
ISO/IEC 25000:2014 Systems and software engineering — Systems and software Quality Requirements and Evaluation (SQuaRE) — Guide to SQuaRE[91]	ISO/IEC JTC 1/SC 7 Software and systems engineering	Essentially, the SQuaRE series offers a good general framework for quality software management, in particular requirements specification and quality evaluation. ISO/IEC 25000:2014 provides guidance for the use of the new series of International Standards named Systems and software Quality Requirements and Evaluation (SQuaRE). The purpose of ISO/IEC 25000:2014 is to provide a general overview of SQuaRE contents, common reference models and definitions, as well as the relationship among the documents, allowing users of the Guide a good understanding of those series of standards, according to their purpose of use. [...]	Accuracy, Quality

Table 8: Standards potentially useful for software

System and Output

The design process of the model involves using an architectural model in Autodesk Revit, which represents a one-storey building with a total area of 225 square meters and 11 windows that can be adjusted in size and orientation to optimize the fitness functions. The software parts and optimization algorithm will be fitted together to provide the semi-optimal solution for this window design.

The objective functions used in the optimization framework are a combined formula consisting of three conflicting objectives. The optimization problem aims to minimize the cost of construction (C), minimize the energy consumption of the building (E), and maximize the daylighting (D) in the occupied zone of the building. These objectives are typically conflicting with each other, resulting in a trade-off that needs to be optimized. The optimization algorithm will balance the trade-off among these objectives to provide the semi-optimal solution for the window design that meets the specified constraints.

The selection process of using the Non-dominated Sorting Genetic Algorithm-II (NSGA-II) algorithm [8] for the optimization framework will be justified by its proven ability to handle multi-objective problems. It is also the case that this algorithm is well-suited for handling conflicting objectives and generating a set of Pareto optimal solutions. Pareto optimal solutions are those that cannot be improved in one objective without sacrificing another objective, meaning they represent the best trade-offs among all objectives. NSGA-II achieves this

89 https://www.iso.org/standard/55154.html
90 https://www.iso.org/committee/45086.html
91 https://www.iso.org/standard/64764.html

by using a combination of techniques like ranking, crowding distance, and elitism. These techniques help to maintain diversity among the solutions and ensure that the algorithm does not converge prematurely to a single solution or a narrow range of solutions. Therefore, by using NSGA-II, this model will be able to provide a set of Pareto optimal solutions that represent the best trade-offs between construction cost, energy consumption, and daylighting in the occupied zone of the building (see Figure 11).

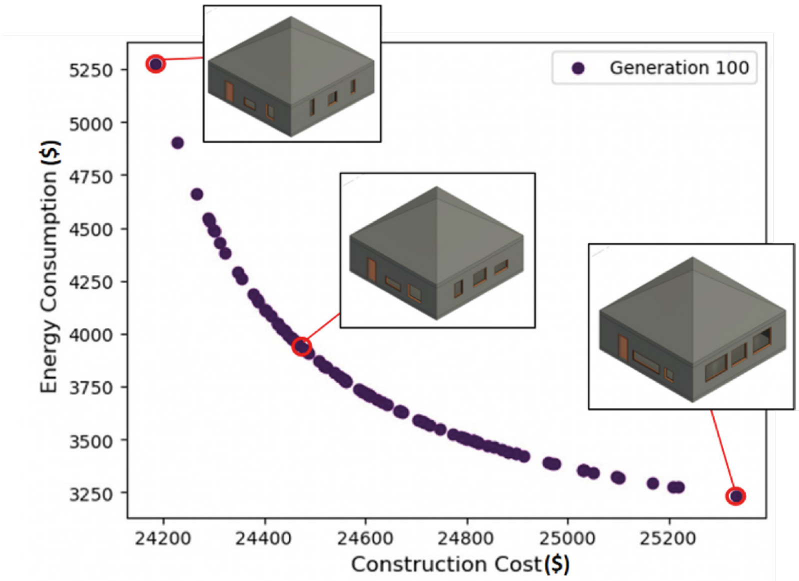

Figure 11: The visualization of a Pareto frontier as a function of Construction cost versus Energy consumption

This will allow decision-makers to choose the best solution that meets their preferences and constraints, and ultimately lead to a more efficient and sustainable building design.

3.2.3. Use case conclusion

Building Information Modelling (BIM) combined with AI offers significant benefits in construction projects, and adherence to standardization plays a crucial role in ensuring their effectiveness. Construction standards provide a reliable foundation for the input data used in BIM systems, ensuring the accuracy and consistency of the optimization results. By following systematic approaches and industry standards, consistent and reliable data can be generated for various building projects. Standardization efforts provide guidance on implementing BIM methodologies and processes, enhancing the reliability and interoperability of BIM data and models.

The use of reliable software solutions, widely employed in the architecture, engineering, and construction industry, further emphasizes the importance of standardization. Incorporating real-world data collected from the industry, such as energy consumption patterns, environmental conditions, and occupant behaviour, enhances the accuracy and effectiveness of BIM models. By integrating such data, the models produce more realistic results, considering the real-world factors influencing building performance. These efforts contribute to creating more sustainable and efficient building designs that comply with regulations and standards.

By leveraging BIM, AI, and optimization techniques while adhering to construction standards, construction professionals can make better-informed decisions, create more reliable and interoperable models, and ultimately achieve cost-efficient, energy-efficient, and daylight-responsive constructions. Standardization ensures that the industry adopts consistent practices and methodologies. It also helps establish trust and confidence in the reliability and accuracy of BIM data, leading to more effective decision-making throughout the construction process.

3.3. Nanosatellite swarms

3.3.1. Introduction and motivation: single-satellite missions and satellite constellations

Ever since the first unmanned satellite launch of the Sputnik satellite in 1957, trustworthiness has always been one of the most fundamental concerns in the space domain: the lack of physical access to satellite equipment once launched vastly increases the importance of ensuring reliability, resilience and availability of the system. As technology has quickly evolved since - pushing applications further – the mitigation of these risks has progressed as well. Nowadays, many satellite missions have been extended to encompass constellations of duplicated satellites, deployed in separate fixed orbits, in order to create a static network and to cover a wider range of areas of interest for its application (e.g. different areas of Earth in observation missions). This approach shows several advantages, such as increased coverage and a distribution of risk, but retains a number of inherent risks to the mission:

- **Lack of flexibility.** The requirements, capabilities and tasks of each satellite are set out in the design phase according to the purpose of the mission. All technical specifications and tests of the satellite during the construction phase are tailored to the precise parameters of this mission; therefore changes to mission parameters at any later stage in the lifecycle of a satellite are unlikely to be tolerated well.
- **Lack of robustness.** Any monolithic satellite represents a single point of failure with respect to the overall mission, since the failure of one satellite will consequently lead to a loss of the mission. This can be compensated to some extent by incorporating redundant systems into the design of the satellite, but the risk cannot be wholly resolved. The use of multiple satellites in a constellation mitigates the risk to the overall mission, but the inflexibility of this mission configuration means that the loss of a single satellite nevertheless reduces mission capability.
- **High cost.** Currently, most major satellite missions involve a ground-up design of a single monolithic satellite tailor-made to the specific requirements of the mission and the use of space-qualified components. This custom design process and the associated testing iterations drive a non-negligible part of the budget requirement for such missions. The need for redundancy in all critical systems further adds to the cost.

These technological risks of the classical mission design approach translate fairly directly to challenges to several trustworthiness characteristics described in Section 1.3, namely:

- **Robustness.** The overall mission should be resistant to failure. With the monolithic design, the fate of the mission is tied to that of a single satellite: its failure necessarily leads to the failure of the overall mission.
- **Resilience.** The mission should be able to recover functionality in the face of adverse events, or degrade functionality gracefully if it is not fully recoverable. With a single satellite, individual components or instruments cannot be replaced. Furthermore, a traditional satellite is generally not able to handle events that were not anticipated in its design, and so has difficulty accommodating changes to the scope of its mission.
- **Reliability.** Challenges to the reliability of the mission follow from the challenges to robustness and resilience.

3.3.2. Technological solution and limitations

3.3.2.1. Swarms of satellites

The New Space approach has changed the space mission paradigm [9]: the involvement of private investors allows for more recurrent launches (e.g. SpaceX[92], Ariane[93], or Blue Origin[94]), more satellites set in orbit per launch (brought forth by the miniaturisation of satellites) and the proposal of new services/missions as direct benefits from on-board computational capabilities increase. The above points have recently been highlighted via a different type of satellite mission: those consisting of multiple, small, fully separated satellites, each capable of communicating with the others and cooperating towards a common goal, using on-board artificial intelligence to accomplish a measure of autonomy. These types of missions are known as autonomous satellite swarm missions [10]. In mitigating the risks discussed in the previous section, such mission formats offer many systemic advantages over the classical satellite mission design. Most importantly, the swarming approach offers (1) flexibility, whereas satellites in a constellation are tied to a fixed purpose; (2) resilience, in enabling members of the swarm to compensate for the loss of others; (3) scalability, in allowing for the extension of a mission beyond its original scope; and (4) cost-effectiveness, in permitting the reuse of satellite designs.

- **Flexibility.** Many satellites with potentially different capabilities can in cooperation accomplish objectives that they were not explicitly designed for, e.g. performing survey tasks. Individual satellites in the swarm can take on different roles depending on the needs of the overall system.
- **Resilience.** Multiple cooperating satellites increase redundancy, since the failure of a single satellite or instrument can be compensated for by others. In a swarm of satellites, only a subset of instruments would be lost, thereby potentially reducing the overall performance of the mission, but not ending it. Indeed, lost individual satellites could be replaced to recover optimal operational performance.
- **Scalability.** The operational performance of a satellite swarm mission need not to be tied to a fixed number of satellites. Careful mission design could allow for a satellite swarm to be launched with a small initial number of satellites and limited mission scope, only to be extended over time by launching additional satellites to join the existing swarm. This would allow for modification of the existing mission in line with evolving technological and scientific advancements and needs.
- **Cost-effectiveness.** The previously discussed characteristics combined lead to the expectation that satellite swarm missions have the potential to be significantly more cost-effective than conventional satellite missions.

However, this distributed mission paradigm poses a number of novel challenges concerning both the required hardware and the need for innovative software solutions.

3.3.2.2. Technological problem characteristics

The need of artificial intelligence for true swarm control

Satellite swarm mission configurations differ from satellite constellations in several respects. Most importantly (1) swarms involve relatively close physical proximity between satellites in a "cloud" formation, (2) swarms involve inter-satellite communication, and (3) members of a swarm, while capable of cooperation, may have separate goals and agency [11]. This combination of independent individual goals and close physical proximity strongly suggests a need for robust real-time decision-making capabilities for each individual satellite in order to avoid collisions and enable cooperation. An autonomous control mechanism would also be required for any swarm of a large number of satellites for simple logistical reasons, as a manual control mechanism of each satellite does not scale well.

92 https://www.spacex.com/

93 https://www.ariane.group/en/commercial-launch-services/ariane-5/

94 https://www.blueorigin.com/

However, the development of artificial intelligence for swarms also has appeal far beyond these immediate control challenges. The distributed configuration of swarms offers new possibilities for approaching complex problems in novel ways, driving progress in the field.

Hardware/power constraints on software solutions

Limited inter-satellite communication

Satellites can communicate with each other, but each transmission consumes energy proportional to the amount of data transmitted. The battery capacity of small satellites is limited, as is the amount of power that can be generated from e.g. on-board solar panels. Therefore, the size and frequency of inter-satellite transmissions should be limited as much as possible to preserve power. In effect, this means that solutions transmitting raw data streams from the satellite are technologically limited.

Limited and delayed Earth-satellite communication

The same power constraints as for inter-satellite communication apply to communication between an Earth-based ground segment and individual satellites, potentially amplified by the need to overcome a greater distance. In addition, the distance between Earth and a satellite introduces a non-negligible latency to any communication between the two. The delay between transmission and reception of a signal may be in the order of minutes or even hours for deep space missions travelling beyond Earth orbit.

As a consequence of these physical limitations, satellites cannot be remote-controlled from the ground in real time and the available data budget needs to be used efficiently. Planned manoeuvres and downlinks can still be carried out by remote commands, but unexpected, time-critical decisions cannot. This problem calls for some level of autonomy of the satellite swarm, enabling satellites to make certain real-time decisions. Similarly, the ability to carry out processing of data on the satellites before transmission to Earth would be valuable, since this allows for a reduction of the total amount of data transmitted.

Limited computing power

Computing hardware deployed in space must be capable of withstanding an adverse environment beyond the specifications that most commercial off-the-shelf (COTS) hardware is designed for. Therefore, custom-designed hardware is often developed and extensively field-tested before deployment. This process leads to increased reliability of the hardware, but considerably slows the transfer of modern state-of-the-art hardware to the space sector.

Coupled with the size, weight, and power budget constraints discussed previously, the computing power available on each satellite in a swarm configuration is limited; any software solution deployed on a satellite is subject to these limitations.

Volatile systems

Individual satellites in a swarm may lose communication temporarily or malfunction permanently. Any system of multiple satellites must be prepared to handle such incidents.

3.3.2.3 Trustworthiness limitations in swarms of nanosatellites

As discussed in a previous section, the design concept of satellite swarms mitigates some of the trustworthiness challenges inherent in the classical design. However, in addition to the modified physical architecture, the operation of true satellite swarms also requires some degree of autonomy to be given to the satellites. This would be accomplished by the deployment of an artificial intelligence, running locally on each of the satellites. In this swarming scenario, the artificial intelligence could then, for example, deal with control problems characterised by a highly complex set of rules, which is difficult to model explicitly. With a machine learning approach, a model of the problem or the solution can be inferred implicitly.

Such an approach, however, introduces a new set of unique trustworthiness challenges related to the distributed architecture of the swarm and the nature of presently existing machine learning approaches.

Inter-satellite cooperation and machine learning

Firstly, the distributed nature of a swarm means that any artificial intelligence system deployed thereon needs to find a balance between enabling the individual behaviour of participants and cooperation between them. For the sake of speed, scalability of the system and robustness to communication loss, each swarm member should be capable of acting independently; yet cooperation within the swarm is also vital. In the example of performing machine learning on a satellite swarm, instead of merely performing machine learning individually on each satellite, satellites could cooperate in sharing information across the swarm. A machine learning model trained jointly by the members of the swarm would be based on a larger and likely more diverse set of training data, generally leading to a better learning outcome.

Inherent black-box nature

The second set of trustworthiness challenges is based on the black-box qualities of current machine learning approaches. The inferences made by a machine-learning model are based on mathematical relationships observed in the training data and as such are often difficult to extrapolate in human-understandable terms. As such, ensuring the safety of models requires additional care, since mathematical models are prone to edge-case behaviours that are counterintuitive in terms of human reasoning. Therefore, unanticipated errors in the model are possible, which could lead to a risk to the flight hardware.

Input data quality

The input data used to train - and later run - the machine learning model also represents a risk in this context. Unresolved biases, corrupted data, and maliciously introduced samples may all serve to distort the training outcome in ways that may not be easy to recognize. Similarly, a fully-trained model may not handle well input data that was not considered in the scope of the underlying training process.

For these reasons, there is also a fundamental need to consider the reliability both of the final machine learning model deployed on a spacecraft and of the learning process producing the said model.

Depending on the particular problem and the selected machine learning approach, testability and qualifiability of the model may also be a concern; e.g. in a model for autonomous mobility control, the quality of model output and thus the capability of the model itself may be difficult to quantify. Indeed, many different trustworthiness characteristics take on different levels of importance depending on the precise application context and the machine learning approach selected.

For the purposes of this study, we focus on examining four main trustworthiness characteristics that arguably bear the greatest general importance in facilitating the deployment of artificial intelligence on spacecraft.

- **Reliability.** The system should execute operations it has been designed for, under given conditions, without any failure. In the current case, it means, be able to run local operations and to contribute to the joint machine learning model (for instance, exchange of data).
- **Robustness.** The system should be able to handle the loss and recovery of communications between satellites and with ground control; individual satellites should be able to still perform reasonably even if not currently linked to each other or a server. Performance can be qualified and quantified.
- **Resilience.** Any machine learning model deployed on individual satellites should be able to compensate for a sudden influx of new and potentially outdated information.

- **Transparency.** The system should record and transmit data that allows for analysis of the machine learning process and decision-making.

3.3.3. Federated learning for swarms of nanosatellites

A possible approach to deploying artificial intelligence for the control of satellite swarms under the technological restrictions outlined above would be the use of Federated Learning (FL). Originally developed for scenarios where several datasets cannot be shared due to privacy constraints, federated learning is a distributed machine learning strategy that allows participants to jointly train a prediction model without exposing their underlying training data. However, the nature of this solution also makes it a promising approach for this use case, where the transmission of data is simply infeasible due to the limitations of available communication links.

Challenge	Description	Federated Learning solution
Communication constraints	Communication is severely limited by satellites' energy budget. Long-distance transmissions are subject to latency.	By transmitting models instead of raw data, the FL approach vastly reduces the number and size of messages required. FL is not reliant on communication with Earth.
Limited computing power	On-board computing capacity is limited by the available hardware and power constraints.	In FL, the computational load of training a machine learning model is shared between satellites.
Volatile systems	Individual satellites may malfunction or temporarily lose communication.	By maintaining models locally, disconnected satellites may remain capable of action. The joint training process can be adapted to handle a variable number of participants.

Table 9: Technological challenges of satellite swarms and how Federated Learning may address them.

The general Federated Learning approach is as follows: each of the participants (known as clients) maintains their own dataset – in the case of satellite swarms this would be the sensor data gathered by the individual satellite. Using only this dataset, each respective client (satellite) trains a local machine learning model. During the local training process, the client intermittently shares information about its local model with the other participants. The local model information from multiple clients can then be aggregated mathematically to craft a more accurate global model. Feedback about this global model is then used by clients to continue the local training process. After repeated training rounds, the final result of this process is a global model that combines the insights of the distributed participants without requiring access to their respective raw datasets.

Research has shown that such federated learning schemes can yield models that perform very well according to the comparative metrics that are usually employed for qualification [12].

The performance of a federated learning scheme is generally qualified by comparing it to a lower and an upper bound. The performance achieved by a single model in a centralised setting, i.e. the setting where a single entity has access to all raw training data known to any client in the distributed setting, is usually considered as an upper bound on the performance achievable by any federated algorithm.

The performance of models trained on individual distributed clients without cooperation often serves as a lower bound on the performance expected of a federated learning scheme. This comparison is useful because if the model obtained by federated learning does not exceed this lower bound, clients gain no benefit from participating in the joint learning scheme.

For some use cases, research has shown that a model computed using a federated learning scheme can, in fact, obtain a prediction accuracy that matches the upper bound. These results demonstrate the promise of the approach and justify the increasingly prevalent use of and research into such algorithms.

However, in other settings with less ideal circumstances, challenges remain [13]. The most common challenges include skewed distribution of data between participants, heterogeneous technological capabilities of participants, and the more general case where participants observe different types of data between them. The lattermost case, known as Vertical Federated Learning in the relevant research field, has only recently begun to be explored.

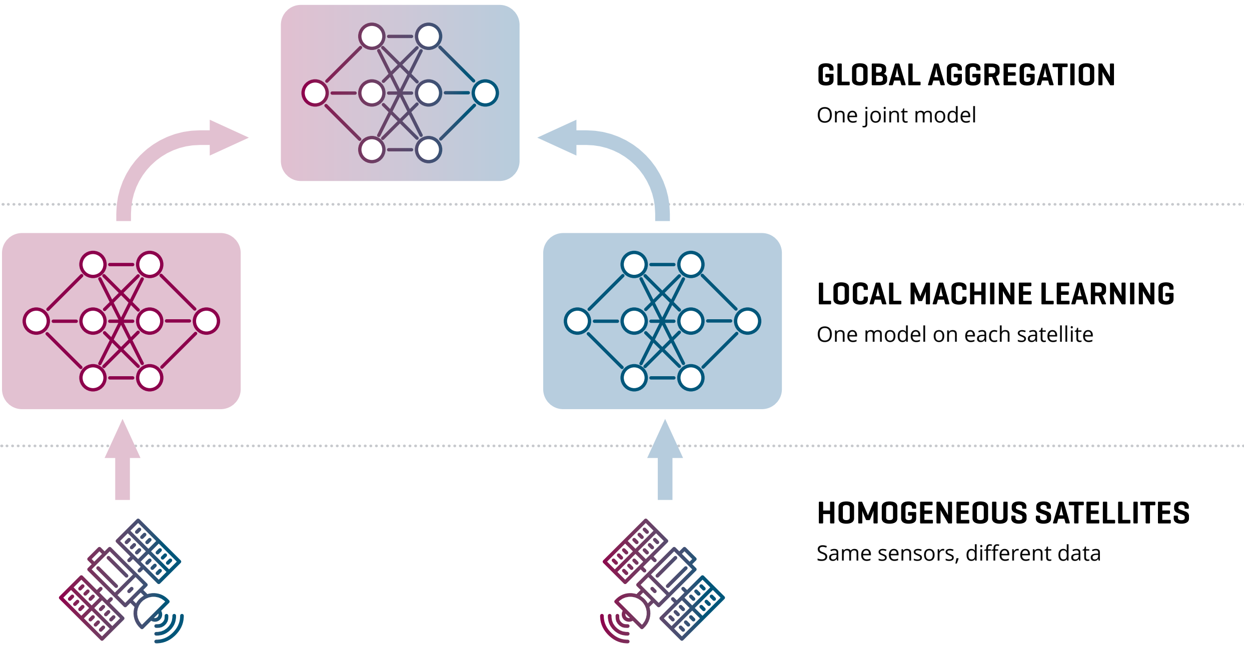

Figure 12: The concept of classical federated learning as it might be used across multiple satellites

3.3.4. Standardization landscape

In the satellite swarm application scenario discussed above, two views of the system must be taken into consideration when discussing applicable standardization in relation to the four trustworthiness characteristics emphasized in Section 3.3.2.3.:

- The system-level view encompasses properties and behaviours of the interacting system composed of all participants (satellites). Here, this includes in particular the model-exchanging behaviour of the federated learning scheme. Standardization for this level would address properties of the federated learning scheme.
- The satellite-level view, on the other hand, covers processes on individual participants, such as the training of a local machine learning model under the federated learning scheme. Related standards could, for example, address the verification, validation and performance assessment of the individual AI models.

A closer analysis of the standardization landscape related to the former (system-level) view shows that, in fact, few standards exist that are directly applicable: KHRONOS' Neural Network Exchange Format, or NNEF[95], ONNX[96], and to a certain extent ISO/IEC 4922-1:2023 Information security — Secure multiparty computation — Part 1: General[97]. Since the use case presented herein currently lies at the edge of technological possibility, and the state-of-the-art in research on federated learning is evolving rapidly, this is to be expected.

Indeed, due to the emergent nature of the research area, the development of general standardization in the short term appears unlikely. The standardization of solutions for well-defined use cases (e.g. satellites) seems perhaps more feasible, so we shall focus on discussing areas relevant to the use case.

One aspect where standardization could be beneficial for the use case is in regulating the exchange of machine learning models between participants of a distributed machine learning scheme, increasing transparency and aiding verification. This question, in fact, is of such immediate importance to stakeholders that two separate industry consortia (those previously mentioned: KHRONOS' NNEF and ONNX) are currently attempting to develop related standards. However, the process of establishing standards in this manner is not transparent and unlikely to find broad appeal – as evidenced by the existence of two competing efforts. A more streamlined approach by the dedicated standardization bodies could yield more comprehensive standards covering a wide range of interests.

In contrast, standardization related to the individual satellite-level view is somewhat more developed, covering e.g. software qualification for space applications and standards specific to the artificial intelligence domain. Owing to the fact that many machine learning developments are extremely recent, various related standards are currently still under drafting. Those that have been completed currently cover mainly general guidance on machine learning systems. We see how these relate to trustworthiness characteristics in Table 10.

95 https://www.khronos.org/api/nnef

96 https://onnx.ai/about.html

97 https://www.iso.org/standard/80508.html

<table>
<tr><th>Standard title</th><th>Standardization committee</th><th>Scope extract/description</th><th>Trustworthiness characteristics affected</th></tr>
<tr><td rowspan="2">ISO/IEC CD TS 8200

Information technology — Artificial intelligence — Controllability of automated artificial intelligence systems[98]</td><td>ISO/IEC JTC 1/SC 42 Artificial intelligence[99]</td><td>This document defines a basic framework with principles, characteristics and approaches for the realization and enhancement for automated artificial intelligence (AI) systems’ controllability. The following areas are covered:
• State observability and state transition
• Control transfer process and cost
• Reaction to uncertainty during control transfer
• Verification and validation approaches
[...]</td><td>Transparency, Robustness</td></tr>
<tr><td colspan="3">Relation to the research topic

While the satellites in the swarm have to have a level of autonomy in order for their overall operation to be possible with minimal interaction from the ground, they ultimately must remain under overall ground control for both mission and safety purposes.

Two main goals can originate from this control action: it can be for observation purposes (transparency) or to execute tasks on the AI model. In both cases, this standard provides procedure in order to execute such operations in a safe way (robustness).</td></tr>
<tr><td rowspan="2">ISO/IEC TS 4213:2022

Information technology — Artificial intelligence — Assessment of machine learning classification performance[100]</td><td>ISO/IEC JTC 1/SC 42 Artificial intelligence</td><td>This document specifies methodologies for measuring classification performance of machine learning models, systems and algorithms.</td><td>Transparency, Robustness</td></tr>
<tr><td colspan="3">Relation to the research topic

Quality control, and in particular performance measurement of the mission necessarily goes through the performance measurement of system components, including the AI on-board.

Assessing machine learning model performance will directly help to answer efficiently the trustworthiness characteristic linked to the technological limitation challenges of space application (power, communication, etc.), i.e. robustness. Additionally, any objective assessment will allow to compare the different model, and will increase transparency of the model.</td></tr>
</table>

98 https://www.iso.org/standard/83012.html
99 https://www.iso.org/fr/committee/6794475.html
100 https://www.iso.org/standard/79799.html

ISO/IEC AWI TS 17847 Information technology — Artificial intelligence — Verification and validation analysis of AI systems[101]	ISO/IEC JTC 1/SC 42 Artificial intelligence	This document describes approaches and provides guidance on processes for the verification and validation analysis of AI systems (comprising AI system components and the interaction of non-AI components with the AI system components) including formal methods, simulation and evaluation. [...]	Resilience, Robustness, Reliability
	Relation to the research topic Currently under development, this document will provide guidelines to validate and verified transparency and reliability of the system. Additionally, heuristic validation of the AI systems will be detailed in this document: in the current space application, this is particularly important when systems have to be embedded on space missions, for obvious reasons of hardware availability		
ISO/IEC TR 24029-1 :2021 Artificial Intelligence (AI) — Assessment of the robustness of neural networks — Part 1: Overview[102]	ISO/IEC JTC 1/SC 42 Artificial intelligence	This document provides background about existing methods to assess the robustness of neural networks.	Robustness
	Relation to the research topic A particular case of quality control/validation for a specific class of machine learning algorithms.		
ISO/IEC 23894:2023 Information technology — Artificial intelligence — Guidance on risk management[103]	ISO/IEC JTC 1/SC 42 Artificial intelligence	This document provides guidance on how organizations that develop, produce, deploy or use products, systems and services that utilize artificial intelligence (AI) can manage risk specifically related to AI. The guidance also aims to assist organizations to integrate risk management into their AI-related activities and functions. It moreover describes processes for the effective implementation and integration of AI risk management. [...]	Resilience, Robustness
	Relation to the research topic Processes to identify, evaluate, and treat risks, in particular through the selection and implementation of controls, as well as a regular iteration of these processes have proven useful in many different contexts (e.g. quality management or information security management). AI has specificities that no other system does, so following this standard methodology is a good, reasonably formalized, starting point for the Machine Learning application. It could be all the more crucial before deployment of an AI-enabled space mission.		

101 https://www.iso.org/standard/85072.html

102 https://www.iso.org/standard/77609.html

103 https://www.iso.org/standard/77304.html

ISO/IEC TR 29119-11 :2020 Software and systems engineering — Software testing — Part 11: Guidelines on the testing of AI-based systems[104]	ISO/IEC JTC 1/SC 42 Artificial intelligence	This document explains those characteristics which are specific to AI-based systems and explains the corresponding difficulties of specifying the acceptance criteria for such systems. This document presents the challenges of testing AI-based systems, the main challenge being the test oracle problem, whereby testers find it difficult to determine expected results for testing and therefore whether tests have passed or failed. It covers testing of these systems across the life cycle and gives guidelines on how AI-based systems in general can be tested using black-box approaches and introduces white-box testing specifically for neural networks.	Transparency, Robustness, Reliability
	Relation to the research topic Although global document on AI, several chapters of this document are useful to understand and answer the trustworthiness characteristics previously identified, for instance transparency. Indeed, the side-effects and the alignment of AI-based systems and human values are detailed. Core content is focused on testing methodologies and advice for AI before deployment.		
CEN/CLC/TR 17603-40-02 Space engineering - Machine Learning Qualification for Space Applications Handbook[105]	CEN/CLC/JTC 5 Space[106]	AI will be a major driver for raising space systems autonomy especially for future exploration activities but also for reducing operations costs of LEO systems and for robotic elements. [...] Therefore the justification of the document is to give guidelines in a handbook on how to qualify ML models for different kind of space software projects while being compliant to the reference standards ECSS-E-ST-40C and ECSS-Q-ST-80C. [...]	Transparency, Robustness, Reliability
	Relation to the research topic Currently under development, this document will increase robustness of Federated Learning in the current application by providing qualification methodologies dedicated to space domain. Integrating AI – which is notoriously fickle and possibly unpredictable in many cases – to the very controlled word of software assurance and testing in space mission system design.		

104 https://www.iso.org/standard/79016.html

105 https://standards.cencenelec.eu/dyn/www/f?p=205:110:0::::FSP_PROJECT,FSP_LANG_ID:73108,25&cs=1364A0C7B22F97A3311A234A8A2289C3A

106 https://standards.cencenelec.eu/dyn/www/f?p=205:7:0::::FSP_ORG_ID:887985&cs=17D471F6F920904967AFC18C2BDA2F89F

ISO/IEC TR 24028:2020 Information technology — Artificial intelligence — Overview of trustworthiness in artificial intelligence[107]	ISO/IEC JTC 1/SC 42 Artificial intelligence	This document surveys topics related to trustworthiness in AI systems, including the following: — approaches to establish trust in AI systems through transparency, explainability, controllability, etc.; — engineering pitfalls and typical associated threats and risks to AI systems, along with possible mitigation techniques and methods; and — approaches to assess and achieve availability, resiliency, reliability, accuracy, safety, security and privacy of AI systems.	Robustness, Resilience, Transparency
	Relation to the research topic This document provides a global overview about the challenges of AI systems in terms of quality, robustness, resilience and transparency. Mitigations measures are presented also in this technical report.		
ISO/IEC 4922-1:2023 Information security — Secure multiparty computation — Part 1: General[108]	ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy protection[109]	This document specifies definitions, terminology and processes for secure multiparty computation and related technology, in order to establish a taxonomy and enable interoperability. In particular, this document defines the processes involved in cryptographic mechanisms which compute a function on data while the data are kept private; the participating parties; and the cryptographic properties. [...]	Robustness
	Relation to the research topic In the setting of federated learning, the local model of each participant is meant to be kept private. Thus, mechanisms that are designed for joint computation in this setting are of primary interest, although the original purpose in the Satellite swarm case is not related to privacy. It remains to be seen how multi-party computation communication requirements compare to those in a non-federated learning case.		

Table 10: Standards applicable to the satellite-level view of the use case.

107 https://www.iso.org/standard/77608.html

108 https://www.iso.org/standard/80508.html

109 https://www.iso.org/committee/45306.html

3.3.5. Use case conclusion

In this case study on autonomous satellite swarms, we have discussed a near-future use case situated at the intersection of multiple relevant fields, most notably artificial intelligence (with a focus on machine learning and federated learning in particular) and aerospace, specifically related to satellites. We analyzed trustworthiness challenges characteristic to the use case and how standardization may help to address these. Our review of related existing and on-going standardization efforts shows that there is a notable variance in the state-of-the-art when compared across sub-fields, in part due to the history and specificities of each field.

On one end of the spectrum lies the standardization related to spacecraft hardware and communication, which has traditionally been very well-maintained. In more recent times, standardization for classical software developed for space applications has largely followed suit, comprising for example extensive guidelines for the validation and verification of such software.

Many standards also exist on the pure AI side, covering different machine learning approaches and application types. While this field is much newer, the use of machine learning is swiftly expanding into many different areas of modern society, attracting the interest of a diverse range of stakeholders. As such, standardization of machine learning techniques is of great importance and, while by no means complete, is progressing rapidly. Standards that are in existence or under development cover e.g. general questions of testing and risk assessment of machine learning systems, but also more specific sub-types of machine learning approaches, e.g. neural networks.

A challenge in the development of such standardization is the rapid pace at which the field is progressing. In some cases, as for the federated learning approach examined in this case study, the subject is so novel that no common foundation of research has been established yet. Ongoing research may be based on fundamentally different concepts and assumptions, with little or no characteristics in common. In such instances, attempts to develop comprehensive standardization would be bound to fail while the respective field remains in an early stage of evolution.

However, targeted standardization within well-defined boundaries remains feasible, and arguably carries an even greater importance in this case, where the pre-existing “common knowledge” of stakeholders may be limited. Here, well-targeted standardization could contribute significantly to raising the level of trust in novel technologies. In particular, there appears to be untapped potential for the development of standardization at the intersection of the different fields of expertise represented by machine learning and satellite systems. Comprehensive standardization in this area could give stakeholders the tools to apply the scientific and technological state-of-the-art with confidence.

Conclusion and outlook

In this white paper, an overview of technical standardization is given, and three research-based use cases are presented, corresponding to the three major growth sectors of the National Standardization Strategy 2020-2030[110] of Luxembourg. The research in each case is conducted by one of three PhD students in the context of the ILNAS-University of Luxembourg research partnership program "Technical Standardization for Trustworthy ICT, Aerospace, and Construction (2021-2024)"[111].

Each use case presentation:

- Extracts various trustworthiness characteristics that underlie its purpose, using as a common baseline the technical specification ISO/IEC TS 5723:2022 *Trustworthiness – Vocabulary*[112] published by the joint technical committee ISO/IEC JTC 1 *Information technology*; and
- Prospectively identifies standardization efforts either existing or to undertake that support that use case's characteristics.

These mappings are encoded and summarized in multiple tables.

Satellite image mosaics. In the case of satellite image mosaics (see Section 3.1), the trustworthiness characteristics of data quality and accuracy are particularly important, in order to obtain the images for the mosaic generation. Standards could be used to harmonize routine satellite pre-processing steps, such as orthorectification. Methods to do this exist, so the way forward is a matter of achieving consensus on them. Standards can also be used to agree on metadata fields in order to enable more effective, transparent, and unambiguous sharing of data images in marketplaces. Algorithmic aspects of image combinations are completely out of the realm of standardization, most likely because the research is still under development.

Building information modelling. There are a wealth of standards that can be used as state-of-the art input to BIM data requirements, essentially due to the fact that the Construction sector itself is arguably one of the most heavily standardized (see Section 3.2). Examples of input include calculation methods, real-world data collection methods, and even general guidelines for information sharing between construction-sector stakeholders. Thus, it would be useful in the future of both BIM standardization and BIM research to systematically consider how to incorporate these standards as input to their own documentation and developments. In terms of trustworthiness characteristics, this is essentially in support of data quality, transparency, and accuracy. Of particular importance is that the overall system's design-time estimations actually correspond to real-world numbers post-construction.

Artificial intelligence in swarms of nanosatellites. The key usage of AI in this case (see Section 3.3) is achieving a level of decision autonomy between swarm participants. Yet, there is too little knowledge intersection between the already heavily standardized field of space vehicles (in terms of hardware or software) and the essentially infant field of general AI. Thus, it is much too early to expect broad efforts towards standardization of AI in general for space mission applications. However, the AI sub-field of Machine Learning seems to be what is serving as the most used paradigm for employing AI in space applications, at least in satellite swarm research. In particular, it is at the heart of Federated Learning. Thus, maturing Machine Learning standards and regularly observing their development can serve as a good starting point, with a view towards considering future Machine Learning standards specifically targeted at space swarm systems. It is worth noting that the trustworthiness characteristics of robustness and reliability are important both for space and for AI, since in each field, control over what might unexpectedly go wrong is paramount, although perhaps for differing reasons. Transparency as well has its importance, namely to be able to trace decisions made, and thus also keep a measure of control.

110 https://portail-qualite.public.lu/fr/publications/normes-normalisation/avis-officiels/strategie-normative-luxembourgeoise-2020-2030.html
111 https://portail-qualite.public.lu/fr/normes-normalisation/education-recherche/normalisation-recherche.html#prog-2017-2020
112 https://www.iso.org/standard/81608.html

The view of this white paper is that it may be possible to systematically consider and design trustworthiness into ICT-supported use cases through a joint effort of:

- Analyzing and breaking down what the essential properties that convey trustworthiness in a given use case actually are. Standards such as ISO/IEC TS 5723:2022 *Trustworthiness – Vocabulary* can be employed to this effect, by for instance classifying trustworthiness characteristics. Note that it could be the case that other domains, even other sub-fields of ICT, may very well have other classifications. In any case, it demonstrates that even efforts to encode in standards concepts as abstract as trustworthiness can be a worthwhile exercise with practical meaning; and
- Focusing efforts on satisfying these essential properties through joint research and standardization work. The use cases as presented show that the proportion of research and standards needed and available may vary quite a lot from topic to topic. Yet, it is always possible to identify either what is missing and that could be useful as a standard, or what is existing and worthy of integration to state-of-the-art.

In its mission to foster in Luxembourg a national normative culture, ILNAS considers interactions between research and standardization as paramount, in particular to get researchers involved in the standardization drafting process. This white paper is an illustration of the potential of this approach in different domains. Being able to grasp these aspects is a non-trivial matter; thus it is also critical that education about standardization be taken into account. To address this, ILNAS[113], the University of Luxembourg[114], and the Luxembourg Chamber of Employees[115] are involved in running a Master's program entitled "MTECH Technopreneurship: mastering smart ICT, standardisation and digital trust for enabling next generation of ICT solutions"[116], which aims to, among other things, give market actors knowledge about the world and usage of technical standardization. It is envisaged in the future to see how further work in line with the outlook of this white paper can also be taken into account in the Master's program going forward.

Market actors are invited to take advantage of all of these opportunities. We would be happy to have you on board[117].

113 https://portail-qualite.public.lu/fr/acteurs/ilnas.html

114 https://www.uni.lu/en/

115 https://www.csl.lu/fr/

116 https://www.uni.lu/fstm-en/study-programs/master-in-technopreneurship/

117 https://portail-qualite.public.lu/fr/normes-normalisation/participer-normalisation.html

References

[1] "Union of Concerned Scientists: UCS Satellite Database," [Online]. Available: https://www.ucsusa.org/resources/satellite-database. [Accessed 15 09 2022].

[2] J. C. Culberson and R. Reckhow, "Covering polygons is hard," *Annu. Symp. Found. Comput. Sci., 601–611 (1988).*

[3] "Geographic vs Projected Coordinate Systems," [Online]. Available: https://www.esri.com/arcgis-blog/products/arcgis-pro/mapping/gcs_vs_pcs/. [Accessed 28 06 2023].

[4] "OpenGIS Geography Markup Language (GML) Application Schema for Earth Observation Products".

[5] O. Ejohwomu, S. A. Adekunle, C. O. Aigbavboa and O. Teslim, "The Construction industry and the Fourth Industrial Revolution: Issues and Strategies," in *Global Trends, Job Burnout and Safety Issues,* Nova Science Publishers, 2021.

[6] R. Sacks, C. Eastman, G. Lee and P. Teicholz, BIM Handbook: A Guide to Building Information Modeling for Owners, Designers, Engineers, Contractors, and Facility Managers, John Wiley & Sons, Inc., 2008.

[7] H. Afshari, W. Hare and S. Tesfamariam, "Constrained multi-objective optimization algorithms: Review and comparison with application in reinforced concrete structures," *Applied Soft Computing,* vol. 83, 2019.

[8] K. Deb, A. Pratap, S. Agarwal and T. Meyarivan, "A fast and elitist multiobjective genetic algorithm: NSGA-II," IEEE Transactions on Evolutionary Computation, vol. 6, no. 2, pp. 182-197, 2002.

[9] O. Kodheli, E. Lagunas, N. Maturo, S. K. Sharma, B. Shankar, J. F. M. Montoya, J. C. M. Duncan, D. Spano, S. Chatzinotas, S. Kisseleff, J. Querol, L. Lei, T. X. Vu and G. Goussetis, "Satellite Communications in the New Space Era: A Survey and Future Challenges,," *IEEE Communications Surveys & Tutorials*, vol. 23, no. 1, pp. 70-109, 2021.

[10] A. Farrag, S. Othman, M. T. and A. ELRaffiei, "Satellite swarm survey and new conceptual design for Earth observation applications," *The Egyptian Journal of Remote Sensing and Space Science*, vol. 24, no. 1, pp. 47-54, 2021.

[11] C. Araguz, E. Bou-Balust and E. Alarcón, "Applying autonomy to distributed satellite systems: Trends, challenges, and future prospects," *Systems Engineering*, vol. 21, no. 5, pp. 401-416, 2018.

[12] B. McMahan, E. Moore, D. Ramage, S. Hampson and B. A. & y Arcas, "Communication-efficient learning of deep networks from decentralized data," in *Proceedings of the 20th International Conference on Artificial Intelligence and Statistics*, Fort Lauderdale, 2017.

[13] P. Kairouz, B. H. McMahan and e. al., "Advances and Open Problems in Federated Learning," *Foundations and Trends®* in Machine Learning, vol. 14, no. 1-2, pp. 1-210, 2021.

Annex

The table below lists the standardization committees responsible for the development of the standards indicated throughout the document, and in particular by the use cases in Chapter 3. More details on many of these committees can be found directly at their websites, in other ILNAS publications such as the Standards Analyses on Construction[118], Aerospace[119], and ICT[120], or the ILNAS White Paper on Artificial Intelligence and Technical Standardization[121].

Committee	Level	Scope extract/description
ISO/IEC JTC 1 Information technology[122]	International	Standardization in the field of information technology.
ISO/IEC JTC 1/SC 27 Information security, cybersecurity and privacy protection[123]	International	The development of standards for the protection of information and ICT. This includes generic methods, techniques and guidelines to address both security and privacy aspects, such as: • Security requirements […]; • Management of information and ICT security […]; • Cryptographic and other security mechanisms […]; […] • Security aspects of identity management […] and privacy; • Conformance assessment […] of information security management systems; • Security evaluation criteria and methodology. […]
ISO/IEC JTC1/SC 7 Software and systems engineering[124]	International	Standardization of processes, supporting tools and supporting technologies for the engineering of software products and systems. […]
ISO/TC 59/SC 13 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM)[125]	International	SC 13 is charged by TC 59 to focus on international standardization of information through the whole life cycle of buildings and infrastructure across the built environment: • to enable interoperability of information; • to deliver a structured set of standards, specifications and reports to define, describe, exchange, monitor, record and securely handle information, semantics and processes, with links to geospatial and other related built environment information; • to enable object-related digital information exchange.

118 https://portail-qualite.public.lu/fr/publications/normes-normalisation/etudes/analyse-normative-construction-mars-2023.html

119 https://portail-qualite.public.lu/fr/publications/normes-normalisation/etudes/standards-analysis-aerospace-sector-june-2023.html

120 https://portail-qualite.public.lu/fr/publications/normes-normalisation/etudes/standards-analysis-ict-june-2023.html

121 https://portail-qualite.public.lu/fr/publications/normes-normalisation/etudes/ilnas-white-paper-artificial-intelligence-and-technical-standardization.html

122 https://www.iso.org/committee/45020.html

123 https://www.iso.org/committee/45306.html

124 https://www.iso.org/committee/45086.html

125 https://www.iso.org/committee/49180.html

ISO/TC 274 Light and lighting[126]	International	Standardization in the field of application of lighting in specific cases complementary to the work items of the International Commission on Illumination (CIE) and the coordination of drafts from the CIE, in accordance with the Council Resolution 42/1999 and Council Resolution 10/1989 concerning vision, photometry and colorimetry, involving natural and man-made radiation over the UV, the visible and the IR regions of the spectrum, and application subjects covering all usage of light, indoors and outdoors, energy performance, including environmental, non-visual biological and health effects and lighting related information modelling systems.
ISO/TC 163/SC 2 Calculation methods[127]	International	Standardization of calculation methods in the field of thermal and hygrothermal performance of materials, products, components, elements and systems, and the thermal, hygrothermal and energy performance of whole buildings, both new and existing, including their interaction with the technical building systems.
CIE International Commission on Illumination[128]	International	[...] The objectives of the CIE are: • to provide an international forum for the discussion of all matters relating to science, technology and art in the fields of light and lighting and for the interchange of information in these fields between countries; • to develop basic standards and procedures of metrology in the fields of light and lighting; • to provide guidance on the application of principles and procedures in the development of international and national standards in the fields of light and lighting; • to prepare and publish standards, reports and other publications concerned with all matters relating to science, technology and art in the fields of light and lighting; • to maintain liaison and technical interaction with other international organizations concerned with matters related to science, technology, standardization and art in the fields of light and lighting. [...]
ISO/TC 163 Thermal performance and energy use in the built environment[129]	International	Standardization in the field of building and civil engineering works • of thermal and hygrothermal performance of materials, products, components, elements and systems, including complete buildings, both new and existing, and their interaction with technical building systems; • of thermal insulation materials, products and systems for building and industrial application, including insulation of installed equipment in buildings; [...]

126 https://www.iso.org/committee/4418564.html
127 https://www.iso.org/committee/53512.html
128 https://www.iso.org/committee/55238.html
129 https://www.iso.org/committee/53476.html

ISO/IEC JTC 1/SC 42 Artificial intelligence[130]	International	Standardization in the area of Artificial Intelligence • Serve as the focus and proponent for JTC 1's standardization program on Artificial Intelligence • Provide guidance to JTC 1, IEC, and ISO committees developing Artificial Intelligence applications
ISO/TC 20/SC 14 Space systems and operations[131]	International	Standardization of manned and unmanned space vehicles that include management of space programs, design, test, production, launch, maintenance, operation, and disposal of space vehicles, and for the environment in which the space programs operate.
ISO/TC 211 Geographic information/Geomatics[132]	International	Standardization in the field of digital geographic information. This work aims to establish a structured set of standards for information concerning objects or phenomena that are directly or indirectly associated with a location relative to the Earth. [...]
CEN/CLC/JTC 5 Space[133]	European	This TC covers all standardization activities in CEN and CENELEC related to space, including dual use aspects, systems of systems, as well as upstream and downstream applications, inasmuch as these topics are not covered by any other existing technical body in CEN or CENELEC or by the European Cooperation for Space Standardization (ECSS) or ETSI, therefore it is important and necessary that it coordinates its work with relevant technical bodies in ETSI. It develops European Standards that are needed to support the implementation of EU-level space projects.

130 https://www.iso.org/committee/6794475.html

131 https://www.iso.org/committee/46614.html

132 https://www.iso.org/committee/54904.html

133 https://standards.cencenelec.eu/dyn/www/f?p=205:7:0::::FSP_ORG_ID:887985&cs=17D471F6F920904967AFC18C2BDA2F89F

October 2023 · Trustworthiness in ICT, Aerospace, and Construction Applications - Scienti ic Research and Technical Standardization. · Version 1.0 · © ILNAS/UNI.LU/ANEC/SnT · ISBN 978-99987-869-7-4

ILNAS
Institut Luxembourgeois de la
Normalisation, de l'Accréditation, de la
Sécurité et qualité des produits et services

uni.lu
UNIVERSITÉ DU
LUXEMBOURG

Southlane Tower I · 1, avenue du Swing · L-4367 Belvaux · Tel. : (+352) 24 77 43 -70 · Fax : (+352) 24 79 43 -70 · E-mail : info@ilnas.etat.lu

www.portail-qualite.lu