University of Maribor

FRAMEWORK PROGRAMME OF EARLY STAGE RESEARCHER TRAINING[1]

1. BASIC DATA

Mentor's name and surname	**MUHAMED TURKANOVIĆ**	Mentor's register number at ARIS (SICRIS):	**39791**
Mentor's e-mail:	muhamed.turkanovic@um.si	Mentor's tel. no.:	+38622207351
Research programme (RP) leader's name and surname:	MARJAN HERIČKO	RP leader's register number at ARIS (SICRIS):	11064
Title of research programme:	Information systems	RP's Register number at ARIS (SICRIS):	P2-0057
Research organisation (RO) of University of Maribor, where training shall be conducted:	Faculty of electrical engineering and computer science	RO Register number at ARIS (SICRIS):	0552-0796
Research field according to ARIS classification:	2.07 Computer science and informatics	Research field according to EURAXESS classification	1.2 Computer and Information Sciences

2. DEFINITION OF RESEARCH PROBLEM AND GOALS OF DOCTORAL RESEARCH[2]

Starting point of research task of the early stage researcher and its position in the research programme, where the mentor is included, work hypothesis, research goals and foreseen result with emphasis on an original contribution to science:

The research work will address the field of decentralized data spaces, with a focus on extending existing architectures such as IDSA (International Data Spaces Association) and Eclipse Dataspace Components (EDC) from the perspective of increasing the decentralization, privacy protection, and the integration of financial mechanisms. The starting point of the research is the already developed DSX Engine (Decentralized Dataspace Connector), which is based on blockchain technology and enables decentralized data exchange without centralized intermediaries. Data spaces represent

[1] *Term early stage researcher (ESR) is written in male form and used as neutral for women and men.*

[2] *Research and study programme of training have to harmonise with contents of the research programme, where the mentor is a member.*

critical infrastructure for the digital economy, as they enable secure, trustworthy, and sovereignty-preserving data exchange between organizations and sectors. However, existing solutions still rely on partially centralized components (e.g., trusted brokers, centralized identity services), which represent bottlenecks and single points of failure. In addition, current implementations do not sufficiently address integration with artificial intelligence technologies (especially federated learning), modern cryptographic approaches for privacy protection (e.g., zero-knowledge proofs), and financial mechanisms for data monetization and automated payments.

The research work will be integrated into the research program of the Information Systems program group (P2-0057) and into the activities of the Blockchain Lab:UM research group, which operates under the Institute of Informatics at UM FERI. The planned research falls under the following research areas of the program group: (1) information systems architectures, (2) intelligent systems, and (3) modern approaches to information systems development.

The research will be conducted in three interrelated but relatively independent thematic tracks, allowing flexibility and dynamic adaptation of the research focus according to technological trends and intermediate results obtained: (A) Support for artificial intelligence in decentralized data spaces – focusing on federated learning over decentralized data infrastructures, data traceability, and explainability of AI models trained on data from data spaces; (B) Privacy support through cryptographic approaches – addressing privacy through the integration of zero-knowledge proofs (ZKPs), smart contracts for data usage control, verification of rights without data disclosure, and comprehensive traceability and verifiability of computational operations; and (C) Support for financial mechanisms and data monetization – including the integration of digital currencies, programmable money, usage-based payments, private payment protocols, and DeFi primitives (collateralization, data-backed loans).

The working hypotheses of the research are: (H1) A decentralized blockchain-based architecture enables greater resilience, autonomy, and transparency of data spaces compared to current partially centralized solutions; (H2) The integration of federated learning into decentralized data spaces enables effective collaborative training of AI models without centralization or disclosure of raw data; (H3) The use of ZKPs and smart contracts for usage control enables rights verification and policy enforcement without disclosing sensitive information; (H4) The integration of financial mechanisms into data spaces enables automated data monetization and new business models.

The following research methods are planned: (1) Systematic literature review (SLR) – covering decentralized data spaces, federated learning, zero-knowledge proofs, and financial protocols in decentralized systems; (2) Architecture evaluation and comparison – design, implementation, and evaluation of prototype architectures and protocols for the thematic areas based on SLR results; (3) Modeling and specification – development of architectural patterns, reference models, specifications, and formal protocols; (4) Experimental evaluation and prototyping – development of prototypes;
(5) Comparative analysis – comparison of the proposed solutions with existing approaches based on key performance indicators; (6) Case studies – application of developed solutions to concrete usage scenarios; (7) Analysis and synthesis methods, deductive and inductive methods – for deriving theoretical contributions from experimental results and vice versa.

The main objective of the research is the design, implementation, and validation of an advanced architecture for decentralized data spaces that overcomes the limitations of existing approaches through the integration of mechanisms for: (1) Collaborative artificial intelligence (federated learning, model explainability, data traceability for training), (2) Cryptographic privacy guarantees (zero-knowledge proofs, smart contracts for usage control, verification without disclosure), (3) Financial mechanisms and data monetization (programmable money, usage-based payments, DeFi primitives).

The research will connect the fields of data spaces, blockchain technology, cryptography, artificial intelligence, and financial technologies into a comprehensive scientific research endeavor.

The research will produce the following key results with original scientific contributions:
(1) A comprehensive SLR of decentralized data spaces with integrated AI, privacy, and finance; (2) A comparative analysis of existing data space architectures with respect to the degree of decentralization, trust mechanisms, privacy support, and financial integration; (3) A reference architecture for a decentralized data space with multidimensional support. The results of the scientific research will be published in international journals with an impact factor (Q1/Q2 journals) covering the fields of data spaces, blockchain technology, artificial intelligence, cryptography, and financial technologies.

3. STUDY PROGRAMME

Foreseen study programme, to which early stage researcher shall be enrolled in academic year 2026/2027:

The training of the researcher will be organized and scheduled in accordance with the study program *Computer Science and Informatics* of the Doctoral School at the Faculty of Electrical Engineering, Computer Science and Informatics, University of Maribor. A more detailed program is available at https://feri.um.si/en/study/programmes/third-cycle/dr/ri/.

The program is designed as a three-year doctoral study with the possibility of an additional completion year, with studies and research activities structured by year as follows. In the first year, the student will fulfill the obligations defined by the curriculum of the first year of the study program, including compulsory and elective courses, examinations, and seminar assignments. At the same time, the student will become familiar with and actively involved in the ongoing research activities of the research group and its projects. The student will conduct preliminary research on the selected topic, define the research domain and challenges, study the relevant literature, and prepare and write initial scientific research (review) papers. The student will also participate in international projects related to the research area.

In the second year, the student will fulfill the obligations of the second-year curriculum, which includes elective examinations, seminar assignments, and individual research work. The research problem will be precisely defined, and the student will focus on intensive research activities. The student will prepare and write original scientific research papers for conference presentations and publication in journals with an impact factor, continue participation in international projects related to the research topic, present research results internally at the institute as well as at local and international events or conferences, and establish domestic and international professional contacts.

In the third year, the student will complete all remaining study obligations and undertake at least a one-month research visit at a foreign research institution, as well as prepare the doctoral dissertation proposal. The fourth year will be dedicated to validating scientific hypotheses, assessing the dissertation's readiness, preparing and submitting the doctoral dissertation, strengthening and establishing international collaborations, and defending the doctoral dissertation.

Based on the topic and scope of the planned research work, and in agreement with the supervisor, the student has selected the following elective courses within the third-cycle *Computer Science and Informatics* study program: *Digital Transformation with Blockchain Technology*, *Unstructured Data*

Mining and Text Processing, and *Software Engineering Effectiveness*. Within these courses, the student will also complete the corresponding seminar units, which will support the research work and contribute to the development of competencies required for the successful completion of doctoral research.

4. DESCRIPTION OF WORK AND TASKS

The tasks arise from the description of the work program from point 3.

5. REQUESTED LEVEL OF EDUCATION

Level VII (7) - Master's degree, 2nd Bologna cycle

6. REQUESTED FIELD OF EDUCATION

061 – Information and Communication Technologies (ICT)

7. KLASIUS SRV

17003 – Master's degree (second Bologna cycle)

8. KLASIUS P

061 – Information and Communication Technologies (ICT)

9. REQUESTED KNOWLEDGE

Knowledge in the field of computer science and information technology and blockchain technologies

10. REQUESTED SPECIAL REQUIREMENTS

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11. REQUESTED LANGUAGES

English, Slovene

12. REQUESTED WORK EXPERIENCE

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13. FORESEEN POSTDOCTORAL TRAINING

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Mentor's signature:

Digitally signed by Muhamed Turkanović
Date: 2026.01.29 19:14:00 +01'00'

Research programme leader's signature:

Marjan Heričko (eOI - podpis)

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DN: C=SI, S=Slovenija, OU=E-osebna izkaznica, ~~OU=Kvalificirani~~ elektronski podpis, SN=Heričko, G=Marjan, SERIALNUMBER=4076097140017, CN=Marjan Heričko (eOI - podpis)
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Name and surname of Dean or authorised person[3]:
prof. dr. Gorazd Štumberger

Signature of dean or authorised person:

Gorazd Štumberger

Digitalno podpisal Gorazd Štumberger
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Barbara Ojsteršek

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[3] The training program is signed by the dean of the member where the ESR's employment and training will take place.