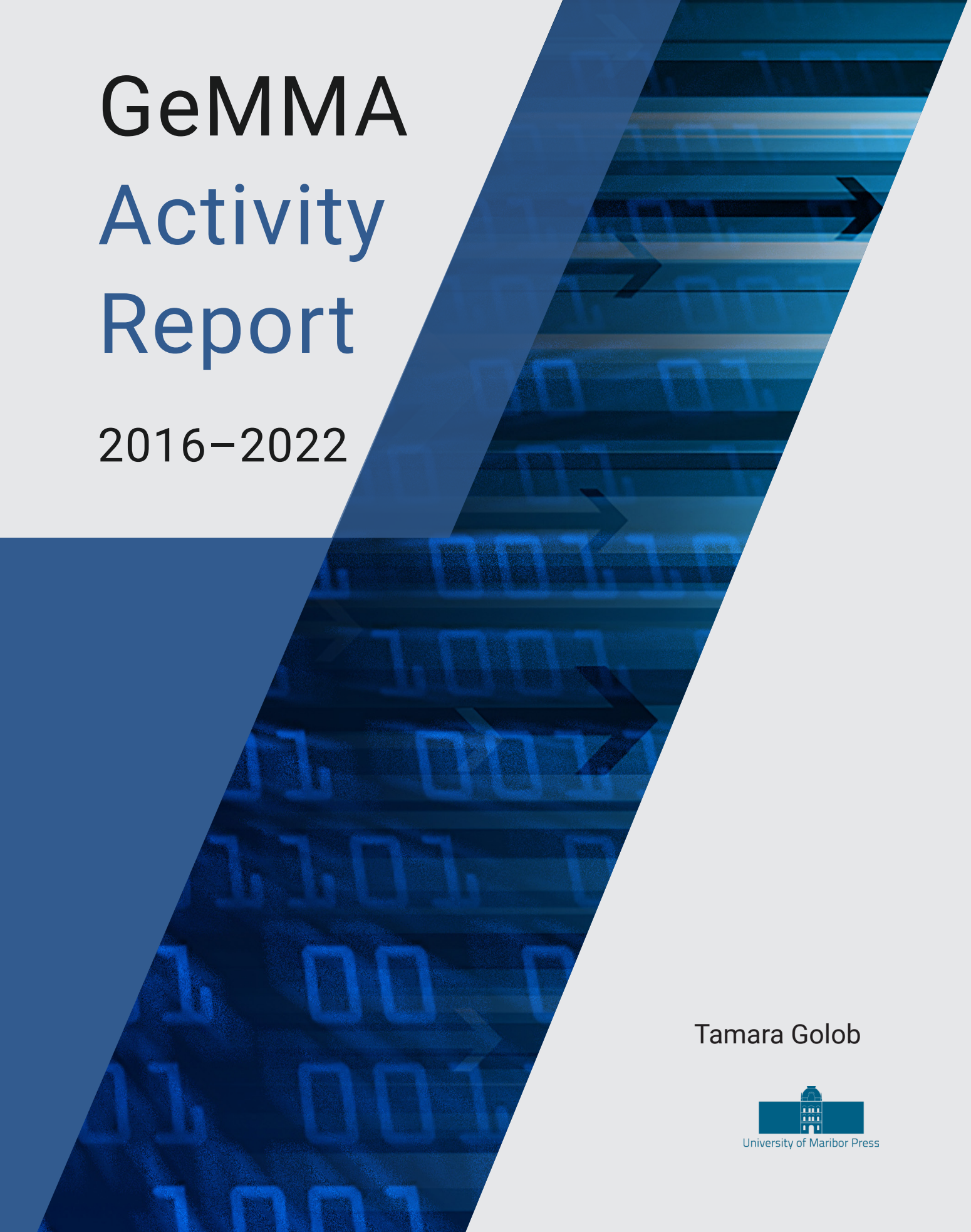
# GeMMA Activity Report

2016–2022



Tamara Golob

University of Maribor Press

# GeMMA Activity Report 2016–2022

Tamara Golob

March 2023

University of Maribor

Faculty of Electrical Engineering
and Computer Science

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# Acronyms

| | |
|---|---|
| 2D | 2-dimensional |
| 2.5D | 2.5-dimensional |
| 3D | 3-dimensional |
| ACM | Association for Computing Machinery |
| AI | Artificial intelligence |
| AIOTI | Alliance for the Internet of Things Innovation |
| API | Application programming interface |
| AR | Augmented reality |
| ARRS | Slovenian Research Agency |
| ARSO | Slovenian Environment Agency |
| BDVA | Big Data Value Association |
| BIM | Building Information Modelling |
| B.Sc. | Bachelor of Science |
| CGAI | Laboratory for Computer Graphics and Artificial Intelligence |
| CH | Cultural heritage |
| CNN | Convolutional neural networks |
| COMPROMISE | Data Compression Paradigm Based on Omitting Self-evident Information |
| DAIRO | Data, AI and Robotics |
| DNA | Deoxyribonucleic acid |
| d.o.o. | Company with limited liability (Sl Družba z omejeno odgovornostjo) |
| EC | European Commission |
| ELES | Slovenian electricity transmission system operator |
| EMS | Energy management system |
| EO | Earth observation |

| | |
|---|---|
| ERDF | European Regional Development Fund |
| ERK | International Electrotechnical and Computer Science Conference |
| ESGO | European Society of Gynaecological Oncology |
| ESP | European Society of Pathology |
| ESRI | Environmental Systems Research Institute |
| ESTRO | European Society for Radiotherapy & Oncology |
| ETSI | European Telecommunications Standards Institute |
| EU | European Union |
| EUROGI | European Umbrella Organisation for Geographic Information |
| FERI | Faculty of Electrical Engineering and Computer Science |
| FGPA | Faculty of Civil Engineering, Transportation Engineering and Architecture |
| FL | Federated learning |
| FST | Fertility sparing therapy |
| GDP | Gross domestic product |
| GeMMA | Laboratory for Geospatial Modelling, Multimedia, and Artificial Intelligence |
| GEOSS | Global Earth Observation System of Systems |
| GFS | GeMMA Fusion Suite |
| GHG | Greenhouse gas |
| GIS | Geographic Information System |
| GISIG | Geographical Information System International Group |
| GPU | Graphics processing unit |
| GZ | Construction Law (Sl Gradbeni zakon) |
| H2020 | Horizon 2020 |
| HPC | High-performance computing |
| ICPC | International Collegiate Programming Contest |
| ICS | Intelligent control systems |
| IEEE | Institute of Electrical and Electronics Engineers |
| IMINT | Imagery intelligence |

| | |
|---|---|
| INSPIRE | Innovation in Science Pursuit for Inspired Research |
| IOT | Internet of things |
| IWW | Inland water ways |
| KPI | Key performance indicator |
| LiDAR | Light detection and ranging |
| MGRT | Ministry of Economic Development and Technology |
| MIZŠ | Ministry of Education, Science and Sport |
| MKGP | Ministry of Agriculture, Forestry and Food |
| ML | Machine learning |
| MNZ | Ministry of the Interior |
| MOP | Ministry of the Environment and Spatial Planning |
| MORS | Ministry of Defence |
| M.Sc. | Master of Science |
| MZI | Ministry of Infrastructure |
| OGC | Open Geospatial Consortium |
| PLACE | Predictive Analytics Based on Location-associated Context Enrichment |
| Ph.D. | Doctor of Philosophy |
| PRO | Patient reported outcomes |
| R&D | Research and development |
| RDP | Research and development project |
| REST | Representational state transfer |
| RNA | Ribonucleic acid |
| RS | Republic of Slovenia |
| S4 | Slovenian Smart Specialisation Strategy |
| SCI | Science Citation Index |
| SERŠ | Secondary School of Electrical Engineering and Computer Science Maribor |
| SMA | Surveying and Mapping Authority |
| TRL | Technology readiness level |

| | |
|---|---|
| UAV | Unmanned Aerial Vehicle |
| UI | User interface |
| UL | University of Ljubljana |
| UM | University of Maribor |
| UMC | University Medical Centre |
| UX | User experience |
| UWB | University of West Bohemia |
| VGI | Volunteered geographic information |
| VLC | Visual light communication |
| WP | Work package |
| WWW | World Wide Web |
| ZUreP-2 | Spatial Planning Act (Sl Zakon o urejanju okolja) |

# Foreword

The predecessor of the *Laboratory for **Ge**ospatial **M**odelling, **M**ultimedia and **A**rtificial intelligence*, the *Laboratory for **Ge**ometric **M**odelling and **M**ultimedia **A**lgorithms* (GeMMA), was established on 1st January 2000. The very early days of the Laboratory, initially having only three members, were characterized with minimal finances and the most elementary equipment (three the most basic personal computers).

The initial research focus was on the algorithms of 2D computational geometry and 3D geometric modelling, especially their efficient and stable implementation in various applications including civil and mechanical engineering, medicine, digital cultural heritage, and geographical information systems (GIS). One of the most remarkable achievements was, when two of our algorithms were incorporated into the AutoDesk development framework (namely, polygon triangulation and polygon trapezoidation). Soon we established a strong cooperation with the Slovene GIS company Igea, d.o.o., and participated in the first European Union supported project Virtual Heart of Central Europe. This, however, gave us the possibility to employ full-time researchers and gain a steep growth of the Laboratory.

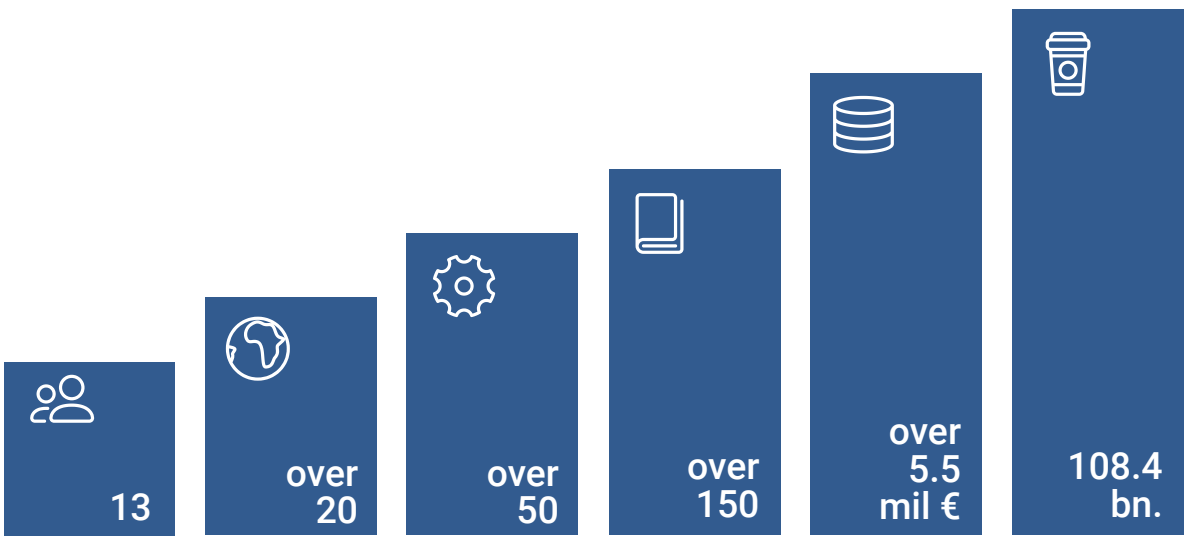
Over the years, GeMMA's research areas have also expanded, including remote sensing data processing, GIS, scientific visualization, data compression, simulation of green-energy resources, big data processing, predictive analytics, and data mining. In 2016, GeMMA unified with the Laboratory for Computer Graphics and Artificial Intelligence (CGAI). With this reunion (the three original GeMMA members also used to work in CGAI before 2000), GeMMA became the strongest research laboratory at the Institute for Computer Science. Since GeMMA was founded, 25 PhDs have been graduated under the supervision of its members. The majority used to work in GeMMA for some period (or they still do). On this basis, the Laboratory has built a team of experienced project leaders who are gaining new research projects at national, European, and industrial level. As the main research orientations changed, the Laboratory was renamed in 2021. GeMMA has 28 full-time employees (10 PhDs, while half of the rest are PhD students) and two part-time members (2 PhDs) at the end of 2022.

The primary aim of this survey is to support the dissemination of the research achievements of GeMMA. It follows the first survey published in 2016, and therefore, the actual book concentrates on the research results since then. The previous book, covering a period of 17 years, presented 35 projects, while the new review of activities over the last 7 years covers as many as 58 projects. This growth is a good cue to introduce the secondary, equally important aim of the book. Namely, we would like to leave the track to our successors to stimulate them for even better research results, to show them, what is possible to achieve in 22 years starting from scratch with the will, hard work, orientation towards the applications, devotion to the research work, and the strong team spirit.

Maribor, November 8th, 2022

**Borut Žalik**
Head of GeMMA

# GeMMA in Numbers since 2016




New members of our laboratory since 2016

International research groups we have worked with in the past 6 years

National, international, bilateral and industrial projects in the past 6 years

Publications of last 6 years

Revenue from projects carried out in the past 6 years

Cups of coffee the lab members drank during working hours in the past 6 years

**Figure 1: GeMMA in Numbers since 2016 (Source: own).**


**Figure 2: A look inside our lab with DroneVIS, tree growth simulator and some projects on display. (Foto: Ž. Ivanc)**

**Figure 3: The other side of our lab with hologram and some projects on display. (Foto: Ž. Ivanc)**

# MEMBERS

# GeMMA Team

## dr. Borut Žalik

Borut Žalik graduated in electrical engineering in 1985 at the Technical faculty in Maribor. The same year he was employed at the same Faculty as a technician and a few months later as a teaching assistant. He obtained M.Sc. and Ph.D. in Computer Science from the University of Maribor in 1988 and 1993, respectively. In 1993, he was elected as an Assistant professor of Computer Science and 5 year later he became Associate professor. In 2003, he was elected as a full professor of Computer Science at the Faculty of Electrical Engineering and Computer Science, University of Maribor (UM FERI). He spent half a year at Technical University Graz (Austria) as a Research fellow in 1992. From 2000 to 2002 he has been the Visiting Research Fellow at De Montort University, U. K. He became the Head of the Laboratory for Geometric Modelling and Multimedia Algorithms (GeMMA) in 2000. Laboratory was renamed in Laboratory for Geospatial Modelling, Multimedia and Artificial Intelligence due to the change in the research focus in 2021. He was the Vice-Dean of Research from 2003 to 2011, and since 2011 to 2019 he was a Dean, both at UM FERI. He was a member of the management board of the Slovenian Research Agency in 2011 and 2012. In 2014 he became the member of the European Academy of Sciences and Arts. He was honoured with the designation of the ACM Senior Member in 2020. In 2021, he became the member of the Professional board of the Maribor University Library. His main research interests include processing of geometric data and compression of multimedia information. He authored more than 145 papers in scientific journals, the majority of them with the impact factor, 11 patents, and supervised 22 Ph.D. students. His hobby is radio-amateurism, where he operates under call-sign S58X.

## dr. Marko Bizjak

Marko Bizjak finished the primary school Braslovče in 2006. During those years he successfully participated in various national-level competitions which allowed him to be awarded with the Zois scholarship. Four years later he finished the Gymnasium Lava in Celje and enrolled in Computer Science and Information Technologies study programme at UM FERI. He completed the programme in 2013 and continued his studies at the same programme on the master's degree level, which he completed two years later. During his studies, he actively collaborated in GeMMA doing research work, for which he received the Andrej Perlach's award, won a student paper competition (SPC) at ERK 2015 and was selected among five finalists of the IEEE Region 8 (Europe, Asia, Africa) SPC 2016. He started his first employment in December 2014 as a technical assistant at UM FERI. Next year he began his Ph.D. study, which he completed in 2019. He now works as a teaching assistant and researcher. His main research interests are remote sensing, environmental simulations and computational geometry, while his hobbies include volleyball, table tennis and football.

## Jan Breznar

Jan Breznar was born on 6th February 1999 in Maribor. He finished the primary school of Sveti Jurij ob Ščavnici in 2014. From 2014 to 2018 he attended the Electrical and Computer School Ptuj, where he graduated as a computer technician. In the same year he enrolled in Computer Science and Information Technologies study programme at UM FERI. He finished his bachelor's studies in 2021 and earned his bachelor's degree in computer science. Currently he is pursuing a master's degree in the same field. From 2019 he is also employed in GeMMA, where he works as a technical associate. His main research interests are GIS, remote sensing and web applications, while his hobbies are cycling, fishing, birding, hiking and reading.

## Matej Brumen

Matej Brumen finished primary school in a town called Benedikt. After enrolling into Secondary School of Electrical Engineering and Computer Science he moved to his old hometown called Jurovski Dol. While he was studying there, he found out the passion for coding. After finishing the secondary school, he decided to pursue computer science career, so he enrolled into Faculty of Electrical Engineering and Computer Science, University of Maribor. Not knowing what he'd expect there he quickly found the study interesting and, therefore, finishing it became his main objective. During his 3rd year he was recruited by GeMMA, the laboratory on the same faculty and started his career there. Soon he graduated and obtained the title »dipl. inž. rač. in inf. tehnol.«. After graduating he enrolled MSc of computer science programme on the same faculty, from which he graduated in 2017. His main interest is exploring modern software engineering practices for minimal development overhead of the project teams, while also contributing code and ideas on the projects. His hobbies consist of playing the guitar and coding.

## Jernej Cukjati

Jernej Cukjati finished the primary school in Prebold in 2010. After that he entered the Gimnazija Celje – Center and graduated in 2014. The same year he enrolled into the Computer Science and Information Technologies academic-degree study programme at the Faculty of Electrical Engineering and Computer Science (UM FERI), which he completed it in 2017. He continued his study on the master's degree level and completed it 2 years later. During this study he also worked as a demonstrator. In 2019, he was employed as a young researcher in GeMMA and began his Ph.D. in computer science, with the focus of his research including the remote sensing data and data fusion. He also works as a teaching assistant.

## Tamara Golob

Tamara Golob was born in Maribor in 1988. After finishing her primary school in Starše, she attended III. gimnazija Maribor. She was accepted at the Faculty of Law Maribor in 2007, where she got her bachelor's degree. She started her career working in non-governmental sectors in various positions, where she has gained industry knowledge and interpersonal skills. She is a member of GeMMA since 2019, where she is working on several EU (H2020, Horizon Europe) and National funded projects, which include project management, coordination, networking, project and financial planning, administration, consulting, and reporting activities. Her hobbies are hiking, playing squash, and traveling.

## Gregor Horvat

Gregor Horvat was born on 13th December 1997 in Maribor. He finished primary school Sladki Vrh in 2012. From 2012 to 2016 he attended Srednja elektro-računalniška šola Maribor, where he graduated as a computer technician. In 2016, he enrolled in Computer Science and Information Technologies programme at UM FERI. He received his bachelor's degree in 2019 and applied for a master's degree the same year. As of November 2022, he is employed at GeMMA as a technical associate and is working on his master thesis. His main research interests are machine learning, mobile application development and data compression algorithms. His hobbies include football, gaming and weightlifting.

## Štefan Horvat

Štefan Horvat was born on 31st of December 1998 in Murska Sobota. He finished primary school of Tišina in 2013. From 2013 he attended secondary school SPTŠ Murska Sobota. After finishing secondary school in 2017, he enrolled in Computer Science and Information Technologies study programme at FERI UM. He received bachelor's degree in 2020 and is currently pursuing master's degree in the same field. Since October 2022 he is employed in GeMMA, where he works as a technical associate. His main research interests are machine learning, GIS, and forecasting. His main hobbies are running, cycling, astronomy and geography.

## Aljaž Jeromel

Aljaž Jeromel finished the primary school Tabor I Maribor in 2010. During that time he regularly and successfully competed in nation-level competitions in math, logic, chemistry and physics. He attended the II. gimnazija Maribor between 2010 and 2014, where he started learning about computers and programming. Because of that, he enrolled into the computer science programme at UM FERI, which he finished in 2017. After graduation, he soon started the employment at GeMMA, firstly as a technical assistant, and, after obtaining the masters degree from the same faculty in 2019, as a teaching assistant. After a one-year pause from studies, he again enrolled into the Ph.D. programme Computer Science and Informatics at UM FERI in 2020. His main research interests include image compression, chain codes, 3D graphics and visualisation. His hobbies are football and playing computer games.

## dr. David Jesenko

David Jesenko was born on 17th October 1990 in Celje. He attended the Primary School Šmarje pri Jelšah between 1997 and 2005. Four years later, he finished the Secondary School of Chemistry, Electrical Engineering and Computer Engineering in Celje. In autumn 2009, he entered the Faculty of Electrical Engineering and Computer Science (UM FERI) at the University of Maribor. He obtained a Bachelor's degree and Master's degree in 2012 and 2014, respectively. He started his first employment in September 2014 as a young researcher in GeMMA. He defended his Ph.D. thesis successfully in April 2018. During his study, he was also a guest researcher at Fraunhofer Ernst-Mach-Institut in Freiburg, Germany in February 2018. He has participated in several research, industrial and bilateral projects. His main research interests are Complex Networks, Evolutionary Algorithms and Machine Learning, while his main hobby is football.

## Domen Kavran

Domen Kavran has obtained a bachelor's degree and master's degree in Computer science at UM FERI in 2018 and 2020, respectively. In 2020, he enrolled in the Ph.D. programme. Since 2018 he has been employed in GeMMA, where he started working as a technical assistant. His work involved web application development for various industrial projects. From 2020 onward, he has worked as a teaching assistant for web development and advanced algorithms undergraduate courses. His main research interests are time series analysis, change detection, pattern recognition, and advanced classification methods with artificial intelligence.

## dr. Štefan Kohek

Štefan Kohek finished the primary school in Ljutomer in 2003. In 2007, he graduated at SERŠ in Maribor as an electrical-computer technician. He entered UM FERI in the same year and in the years 2010 and 2012 obtained B.Sc. and M.Sc. in computer science, respectively. During the study he was occupied by a sole proprietorship as a programmer. In 2012, he became a technical assistant in the CGAI lab at UM FERI and from 2013 onward he is employed as a teaching assistant. By joining the former laboratory to GeMMA in the year 2016, he has also joined the new laboratory. In 2019, he obtained a Ph.D. degree in computer science. His current research interests include computer graphics, tree growth simulation, optimization techniques, parallel computing, and remote sensing data.

## Denis Kolednik

Denis Kolednik finished the primary school of Benedikt in 2004. Later he attended the Secondary School of Electrical Engineering and Computer Science Maribor – Technical gymnasium and finished in 2008. He started his study path at the UM FERI in 2008. In 2011, he finished his Bachelor studies (1. bologna degree) of Computer science and information technologies. In 2013, he finished his Masters studies (2. bologna degree) of the same study programme and got his first employment as a technical assistant in GeMMA in August 2013. Half a year later he started his research career as a researcher at GeMMA. From 2014 to 2017 he was also a teaching assistant. His current research topic is Geographic Infromation Systems. His main hobby is bicycling. During this study he also worked as a demonstrator. In 2019 he was employed as a young researcher in GeMMA and began his Ph.D. in computer science, with the focus of his research including the remote sensing data and data fusion. He also works as a teaching assistant.

## dr. Simon Kolmanič

Simon Kolmanič finished the primary school Ormož in 1987. He continued his education at the Secondary School of Natural Sciences and Mathematics Ptuj, which he completed in 1991. During that time, he got his first computer Commodore 64, and discovered the beautiful world of programming and computer graphics. Consequently, he continued with his education on UM FERI where he finished the study in 1996 with a B.Sc. degree. In the same year, he joined the CGAI lab in the same institution as a technical assistant. In 1997 he started his M.Sc. study, which he finished in 1999. In the same year, he also started working as a teaching assistant. In 2000, he started his Ph.D. study, which he finished in 2005. In 2016 the CGAI lab joined GeMMA, where he continues with his work. During his work in CGAI lab, he started working in the field of computer animation, which is still one of his main interests. He is also interested in the virtual and augmented realities and computer simulations of vegetation growth and ecosystems. Between 2006 and 2011, he was a member of the Electronic Communication Council of the Republic of Slovenia. Currently, he is an assistant professor and is giving lectures in the field of algorithms, computer graphics, and computer animation.

From the mid of eighties, when he got his first camera, he has been in love with photography, which is his main hobby to this day. He is also active as a volunteer firefighter in Voluntary Fire Department Ormož, where he was also a fire chief between 2003 and 2011. From time to time, he can also be found as an actor on a stage with some quite successful performances behind him.

## dr. Bogdan Lipuš

Bogdan Lipuš completed the primary school in Oplotnica in 1990. In 1994, he successfully finished SERŠ in Maribor. After that, he entered UM FERI and graduated in computer science in May 2000. In his student days in December 1999, he started to work as a technical assistant in the CGAI lab. In 2000, he got a position as a young researcher and entered the M.Sc. programme. After obtaining M.Sc. in computer science in 2003, he continued his study and received his Ph.D. in computer science in 2005. For two and a half years he worked as a software developer in Hermes Softlab. Returning from industry, he started to work in GeMMA. He participated in several applicative and scientific research projects. Since 2015, he was elected as an assistant professor of computer science. His research interests include point cloud processing, remote sensing, computer graphics, processing of geometric data, data compression, and image processing. Currently, he works mostly on industrial projects. His hobbies include cooking, gardening, walking, running, and cycling.

## Luka Lukač

Luka Lukač was born on 13th of February 2000 in the small town of Murska Sobota. After finishing primary school of Bakovci in 2015, he crossed the Mura River in order to enroll at Franc Miklošič High School in Ljutomer, which became his second home until 2019. During that time, he grew fond of computers, mathematics and physics. Therefore, in 2019, he decided to start his studies at FERI UM in Computer Science and Information Technologies study program. Besides obtaining his bachelor's degree in 2022, he started working in GeMMA as a technical associate, where his research interests are focused on GIS and data compression. His main hobbies are participating at trivia quiz events, doing several sports, watching splendid movies and reading great books.

## dr. Niko Lukač

Niko Lukač is an Associate Professor in the field of Computer Science at Faculty of Electrical Engineering and Computer Science, University of Maribor, Slovenia. He completed his Ph.D. study in Computer Science at University of Maribor in 2016 under Young Researcher Ph.D. study scholarship. During his Ph.D. studies he was also a visiting Ph.D. student at German Aerospace Center (DLR) and Heidelberg University, in 2014 and 2016, respectively. Soon after completing his Ph.D. study he was habilitated as Assistant Professor in 2017, and as an Associate Professor in 2022.

His research focus is in the following areas: geospatial data analytics, simulations and modelling, parallel computing, and applied artificial intelligence. In the past years he has co-authored several journal papers indexed in Science Citation Index (SCI), international conference papers, book chapters, and received a US patent grant. In the given timeline he has also successfully coordinated various R&D projects at national and international level. As an Associate Professor at UM FERI, he is also active pedagogically, by providing thesis supervision and lectures for undergraduate and postgraduate students.

During the timeline 2019-2022 he was an executive committee member of the European Umbrella Organisation for Geographic Information (EUROGI). From 2018 to 2022 he also served as the Section Editor for the Computer Science field at the open access journal Data in Brief, while during the years 2020-2021 he also served as a Topic Editor for ISPRS International Journal of Geo-Information. In 2022 he also took part in expert evaluation process of Innovation Action (IA) type of proposals for the European Commission, under the Horizon Europe programme. In 2019 he has received recognition at the University of Maribor for outstanding research achievements.

# dr. Domen Mongus

Domen Mongus was born in Slovenj Gradec in 1982. He spent his youth in a small village beneath the Carinthian Mountains, by the name of Podgorje. After the elementary and secondary schools, he left for Maribor to study computer science at UM FERI. In 2007, he started to work in GeMMA. He defended his diploma thesis in 2008 and started working as a Young Researcher, funded by the Slovenian Research Agency. He concentrated his work on Environmental Intelligence, joining the fields of data fusion, remote sensing data processing, geometric pattern recognition, and artificial intelligence.

In 2012, he completed his Ph.D. and became an assistant professor at UM FERI. In the same year, he received an award for research excellence at UM FERI. In 2013, he received an award for pedagogic excellence at UM FERI, while the Slovenian Research Agency awarded him for Exceptional Achievement in Science in 2014. In 2015, Slovenian National Radio and Television, Val 202, named him as “The Name of the Week”. In the same year, he received the highest award in the field of Information Society in Slovenia for ongoing work. He was also named as Young Scientist of Danube region by Danube Region and Central Europe and Austrian Federal Ministry for Science, Research and Economy. In 2018, he received the highest institutional academic award for exceptional contributions to scientific and pedagogical reputation and excellence of University of Maribor, and was awarded for exceptional research achievements in 2019 at University of Maribor, Faculty of Electrical Engineering and Computer Science.

From 2008 to 2012, Domen Mongus was a member of the Executive Committee of ACM Slovenia. From 2013 to 2019, he was a member of the Executive Committee of European Umbrella Organization for Geographic Information (EUROGI) and is a member of Executive Committee of GISIG from 2020.

## Andrej Nerat

Andrej Nerat was born on 6th October 1980 in Maribor. Since early childhood he developed interest in computers, first an old ZX Spectrum, later PCs. After he finished primary school in Ceršak and later Šentilj v Slovenskih goricah in 1995, he continued his education at SERŠ in Maribor. In 1999, he first entered UM FERI, where he has been since then. He spent the first five years there as an undergraduate student in computer science. After graduation in 2004 he joined the CGAI lab. He has worked there as a technical assistant. In 2016, he joined GeMMA to continue working at the same position.

## Sašo Pečnik

Sašo Pečnik was born in Maribor in 1985. He finished primary school in Miklavž in 2000. Four years later he finished SERŠ in Maribor as a Computer Technician and then entered UM FERI, where he graduated in Computer Science as the best of his class in 2007. Two years later he received his MsC. In 2008, he was noticed by his professor and mentor Borut Žalik who gave him his first employment in GeMMA. He entered a Ph.D. study program of Computer Science and was promoted to a researcher in 2010. In 2014, he became a teaching assistant at UM FERI. Between 2014 - 2015, he worked as part-time researcher at the Company Lineal d.o.o. in Maribor. Along with the Lineal team, he was awarded at CITA Smart Collaboration Challenge 2014 in Dublin with the 1st place for the project RO3D-SMART. His main research interests are processing and visualization of LiDAR data along with computer geometry, computer graphics, CAD and cloud computing, while his hobbies are running, football and travelling.

# dr. David Podgorelec

David Podgorelec finished primary school Maks Durjava in Maribor and Secondary School of Natural Sciences and Mathematics (the present-day II. gimnazija Maribor) in 1982 and 1986, respectively. He graduated in computer science at the Technical Faculty (predecessor of UM FERI) in 1993 and found his first employment as a programmer in MIPS d.o.o. in Maribor in 1994. In autumn 1995, he got a position of a young researcher at UM FERI, but soon changed it to a teaching assistant position. After four years in the CGAI lab, he moved to GeMMA in 2000 as one of its three original members. He obtained M.Sc. and Ph.D. in computer science from UM in 2000 and 2002, respectively. During 2004–2005, he spent 7 months at the University of Luton (current University of Bedfordshire) in the United Kingdom as a research fellow. In subsequent 10 years, he worked as assistant professor of computer science at UM FERI. Between April 2012 and February 2015, he was a head of the Media Communication Institute at UM FERI. In October 2015, he completed his assistant professor career, but he returned to GeMMA in March 2016 as a researcher. He has remained in this position until now, with the exception of the last third of 2018 when he was employed at the University of Ljubljana. In his prime, he used to climb mountains and play football as hobbies, which he traded for cycling, mushroom picking and dog-walking in his mature years.

## Blaž Repnik

Blaž Repnik finished the primary school Črešnjevec in 1998. Four years later he finished SERŠ in Maribor. In 2002, he entered UM FERI where he got the bachelor degree in 2007. He started working in GeMMA in 2006 as a technical assistant. He entered the Ph.D. study programme of Computer Science and was promoted to researcher position in 2013. His main research interests are GIS, dynamic systems and 3D graphics.

## dr. Damjan Strnad

Damjan Strnad graduated from computer science and informatics at UM FERI in 1998. He upgraded his education through the M.Sc. in 2000 and Ph.D. in computer science and informatics in 2006. For his study excellence he received the university chancellor's award. In 1997, he was employed as a technical assistant in the CGAI lab. He continued working in CGAI as an assistant during 1998-2007. Since becoming the assistant professor in 2007 and the associate professor in 2012, he is giving lectures in the field of computer science, particularly computer graphics and artificial intelligence. The latter is also his main research interest. He has been working as a supervisor for several diploma candidates and is currently mentoring a Ph.D. candidate. He joined GeMMA at the start of 2016.

## Niko Uremović

Niko Uremović finished his primary schooling in Maribor in 2013. Four years later, he finished II. gimnazija Maribor. He obtained bachelor's degree in 2020 on University of Maribor, Faculty of Electrical Engineering and Computer Science. He started his first employment in September 2020 as a young researcher at UM FERI. During his studies at secondary school he was a recipient of the Zois scholarship for outstanding students. His main research interests are machine learning and IoT, while his main hobbies encompass reading, spending time with family and training his dogs.

## Dino Vlahek

Dino Vlahek was born in Čakovec in 1992. He spent his youth in a small village in Međimurje County, by the name of Čukovec. After finishing the primary school called OŠ Sveta Marija in 2006 and, four years later, the Gymnasium in Čakovec, he went to obtain the bachelor's degree in computer science at The Polytechnic of Međimurje in Čakovec. After earning it, he worked in the private sector as a computer programmer for a few years. In 2016 he entered the M.Sc. study program of informatics and technologies of communication at UM FERI. He defended his master's thesis in 2018 and was recruited by GeMMA, building his career as a researcher. At this point, he also started his Ph.D. study in Computer science and informatics at UM FERI. His current research interests are feature learning, data analytics, and model interpretation.

## Mitja Žalik

Mitja Žalik finished the primary school Kamnica in 2013. In the next four years, he attended grammar school II. gimnazija Maribor, where he started to learn programming. During that time, he successfully competed in several national competitions, mainly in physics, mathematics, logic and programming. In 2017, he qualified and participated in Central European, Balkan and International Olympiads in Informatics. In the same year, he enrolled in the Computer Science and Information Technologies programme at the UM FERI. In 2019 he started to work in GeMMA as a technical assistant. He obtained a bachelor's degree in 2020. Two years later, he finished his master's degree and became a teaching assistant. While studying, he was a member of the team that successfully participated in various programming competitions (ICPC Slovenian Programming Contest - UPM, ICPC Central Europe Regional Contest – CERC and IEEEXtreme). Currently, he is enrolled into a doctoral degree study program. His research interests include edge computing, geospatial data processing and convolutional neural networks.

## Aljaž Žel

Aljaž Žel was born on 22nd of June 1999 in Maribor. He finished primary school Prežihovega Voranca Maribor in 2014. From 2014 to 2018 he attended II. gimnazija Maribor. After finishing secondary school he started his studies at UM FERI. In 2021, he received his bachelor's degree. Currently he is enrolled in computer science master's degree. In secondary school and university he received Zois scholarship for outstanding achievements. In 2021 he started to work in GeMMA, where he currently works as a technical associate. His main research interests are GIS, machine learning and computer graphics. His main hobby is running.

## Denis Žganec

Denis Žganec finished his primary school in Štrigova. From 1999 to 2003 he attended the secondary school of Technical School in Čakovec, where he graduated as a computer technician. In 2005, he was accepted to UM FERI in order to study computer science. He obtained bachelor's degree in 2012, and he is currently finishing his master's. From 2008 he is also employed in GeMMA, where he works as a technical associate. His work is mainly concentrated on the development of GIS.

# Part-time members

| | YEARS ACTIVE |
|---|---|
| | FROM |
| **dr. Simon Jurič** | 2014 |
| **dr. Krista Rizman Žalik** | 2004 |

# Past members

| | YEARS ACTIVE | |
|---|---|---|
| | FROM | TO |
| **Robi Cvirn** | 2015 | 2018 |
| **Roman Čuk** | 2013 | 2013 |
| **dr. Vid Domiter** | 2004 | 2011 |
| **dr. Simon Gangl** | 2010 | 2014 |
| **dr. Matej Gomboši** | 2000 | 2006 |
| **dr. Denis Fekonja** | 2012 | 2017 |
| **Valentin Kerman** | 2018 | 2021 |
| **dr. Gregor Klajnšek** | 2001 | 2010 |
| **Primož Kovačič** | 2012 | 2013 |
| **dr. Sebastian Krivograd** | 2000 | 2009 |
| **Žiga Leber** | 2015 | 2018 |
| **Simon Lušenc** | 2013 | 2014 |
| **Renato Mikša** | 2009 | 2010 |
| **Denis Obrul** | 2006 | 2015 |
| **Amadej Pevec** | 2015 | 2018 |
| **Boštjan Pivec** | 2004 | 2015 |
| **Damjan Roškar** | 2014 | 2015 |
| **dr. Bojan Rupnik** | 2006 | 2013 |
| **dr. Gregor Smogavec** | 2008 | 2014 |
| **Tadej Stošić** | 2018 | 2022 |
| **dr. Denis Špelič** | 2004 | 2018 |
| **Jan Tovornik** | 2018 | 2019 |
| **dr. Mirko Zadravec** | 2001 | 2008 |
| **dr. Eva Zupančič** | 2017 | 2020 |
| **dr. Danijel Žlaus** | 2011 | 2022 |

# PROJECTS

Slovene National Projects

International Projects

Bilateral International Projects

Industrial Projects

# Slovene National Projects

# Computer Systems, Methodologies and Intelligent Services - Programme Funded Unit

Programme Funded Unit (PFU)– Computer Systems, Methodologies and Intelligent Services started in 1999 and is implemented in five-year funding periods (with the exception of the last period, which lasts 6 years). Research goals in the PFU are adapted to current trends in computer science. Since the begining, researchers from most laboratories of the UM FERI Institute of Computer Science participate in PFU. In the last two funding periods, which are briefly described in this chapter, the participating laboratories are:

- Computer Architecture and Languages Laboratory;
- Laboratory for Geospatial Modelling, Multimedia and Artificial Intelligence (GeMMA);
- Laboratory for Heterogeneous Computer Systems;
- Programming Methodologies Laboratory;
- System Software Laboratory.

**Financed by**

ARRS – Slovenian Research Agency (contract P2–0041)

**Duration**

1999 to 2025

**Aditional information**

**http://p2-0041.feri.um.si/2015_2019/**
**https://p2-0041.feri.um.si/**

## Period 2015-2019

The research examined the common features and laws of unstructured and heterogeneous massive data sources and flows we encounter on a daily basis in computing and informatics (e.g. World Wide Web, Earth surface data acquisition systems, biomedical systems). Their scope, dynamics and diversity offer many research challenges, the primary goal of which is to unify their processing at the appropriate level of abstraction. For this purpose, we have broken down individual data sources and streams, which are usually immersed in strong information and instrumental noise, into basic semantic building blocks (symbols), which enabled their efficient noise reduction, structuring and alignment. Advanced data enrichment methods were implemented in the form of weakly merged services, the orchestration of which led us to a wide range of user applications.

To this end, we have integrated key research paradigms into a three-tier service architecture, where the first level took care of domain-specific data resource management and interoperable access to second-level services. This level was focused on data enrichment, and we paid a lot of attention to obtaining basic data building blocks. We focused primarily on the development of two recently proposed paradigms: **algebraic formalization of attribute filters** based on mathematical morphology, and **analysis of hidden components**. The first paradigm allows accurate estimation of sample properties by selectively and fully automatically adapting the required geometric structures to input data sets, while the second paradigm exploits the time-space dependencies of data building blocks (symbols) to separate composite data streams from different sources.

We looked for heuristic knowledge about the characteristics of the obtained basic data building blocks with the help of machine learning algorithms and connected them into multi-meaning sets through their mutual relations. The last level of our architecture was the application level, where we used the services of the second level and show their universality and interoperability in very different areas.

Typical examples include the detection of irregular muscle contraction with the help of non-invasive surface electromyograms and the assessment of changes in the earth's surface due to landslides, water or wind erosion. Both of these applications address current socio-economic challenges and are linked by the rapidly rising costs of demographic and climate change. Extensive information support based on the collection and credible interpretation of verifiable data is crucial for the effective adoption of strategies at national and European level. The proposed development of computer algorithms has enabled more efficient, reliable and faster processing of existing databases in these areas, and thus greatly supported many other scientific fields.

## Period 2020-2025

Growth in Internet of Things (IoT) investments, mass data analysis, and artificial intelligence has spurred the development of digital copies of real-world entities in the form of digital twins. Such cyber-physical systems offer advanced monitoring, data analytics, and prognostic capabilities, making them a new trend in computing. Gartner ranks them among the top 10 technologies in 2019, with an expected 37% annual growth rate from the current $ 2 billion to $ 15 billion in 2023 and $ 26 billion in 2025. With the ability to anticipate potential problems and find optimal solutions, such digital twins can offer significant help in treating patients and help reduce risks and increase treatment effectiveness.

Nevertheless, today the use of digital twins is limited mainly to highly controlled environments and smart machines. However, the development of technologies to mimic more complex systems related to the functioning of the human body still faces the following important challenges:

- Processing the set of heterogeneous data streams needed to learn the behavior of the observed system requires significant improvements in methodologies for **automatic data alignment and structuring**;
- Existing methods of merging medical data and learning characteristics are still focused mainly on the isolated processing of individual data sources. This requires the development of new methods that will be able to make **better use of their complementarities**;
- Linking biomedical measurements with environmental and lifestyle factors, which is essential for the transfer of laboratory observations to real environments, requires significant advances in methods for e**xtracting contextual characteristics**;
- Methodologies for monitoring living microhabitats need to be improved, as high dispersion of environmental sensors creates large spatial and temporal gaps in the obtained informations;
- The need to personalize digital twins requires the **optimization of dynamic models** and their **adaptation to the observed persons**, which exceeds the capabilities of modern optimization algorithms.

As part of the proposed work program, we intend to upgrade our previous research work and address the described challenges with the aim of implementing **a digital twin that will be able to mimic the functional parameters of the human nervous and muscular system in the real environment**. Due to the general aging of society, neuromuscular diseases are becoming an important health risk and a leading cause of incapacity for work. The costs associated with such diseases in Slovenia exceed 2% of GDP.

The program group brings together leading experts in the processing of neuromuscular signals and semantic data, development of methods of temporal and spatial analysis and implementation of optimization algorithms that will implement the proposed program in a co-creative way based on a focused iterative work plan.

Picture below shows the developed web platform for the digital twin, where a given test subject who is anonymized has several attached sensors (e.g. heartbeat), which can then be visualized and analysed by the platform. The platform enables fusion of time series sensor data from the test subject, with time series sensing data from stationary sensors (e.g. weather stations) as well as Earth observation (EO) data (e.g. satellite imagery).

# Morphological Operators for Pattern Recognition in Large Point Clouds

## Financed by

ARRS – Slovenian Research Agency (contract J2–5479)

## Duration

2013 to 2016

## Partners

UM Faculty of Electrical Engineering and Computer Science, Geodetic Institute of Slovenia

The advanced technologies of laser scanning with their accuracy, speed and resolution, have revolutionized the field of Earth observation. The amount of information contained within 3D point clouds has introduced the recognition of geometric structure as the most important computational challenge of this decade. Developing new solutions requires coping with irregular point distribution, the lack of topology and their sheer size that often exceeds the capabilities of modern computer systems. Using the known concepts that were developed for pattern recognition in raster data leads to inefficient algorithms that require intensive user interaction and additional information about the geographical areas.

The proposed project's intention is to research a **new methodology for recognizing 3D geometrical structures, monitoring their dynamics, and detecting events within large point clouds**, as acquired from scanning the Earth's surface by applying contemporary findings of mathematical morphology.

Although, mathematical morphology is considered to be a young mathematical theory, its quantitative arithmetic of shape description offers great expressional strength. Morphological operators are derived from the set theory and extended by using the concepts of geometry, topology, probability, and statistics, and are completely adapted for digital and parallel processing. The recently developed algebraic formalization of scanning morphology offer a spatially-dependent, selective, and completely automatic adaptation to the geometrical structures of input data. These theoretical foundations offer the possibility of developing an efficient pattern recognition methodology, where adaptation to the temporal domain would allow a quantitative presentation of events and a description of the dynamics.

The efficiency of the developed method would be demonstrated with by two uses:

- **Recognition of geomorphological process kinematics and**
- **Monitoring tree development in Slovenia.**

For the purpose of recognizing the kinematics of geomorphological changes (such as landslides) it is intended to develop an automatic method for ground recognition within 3D point clouds, and the construction of a digital elevation model that would be more accurate and time efficient without the need for users to set parameters. Such a procedure would allow for the detection of changes in the terrain and evaluate the volume, mass and speed of moving earth masses over large geographical areas (whole of Slovenia) with high resolution (under 0.5m) and accuracy (over 90%). Similar accuracy can be expected regarding (ii) monitoring tree development, where a new method for recognizing single trees would be developed. This method would estimate the number of trees within a respected area and provide the geographical positions, heights and volumes of tree-crowns. It would measure growth of a single tree, wood biomass growth by cyclical data acquisition, and develop a predictive simulation of their development.

The precision of the proposed uses would be tested by on terrain measurements, while the construction of a digital elevation model of Slovenia will demonstrate their computational efficiencies. In this way, the national project for surface scanning of Slovenia with LiDAR technology would be supported directly. The results of our research will be published in the most distinguished international journals, and regularly presented to the Slovenian public by organizing symposiums and workshops. It will also promote our products abroad by attending international conferences.

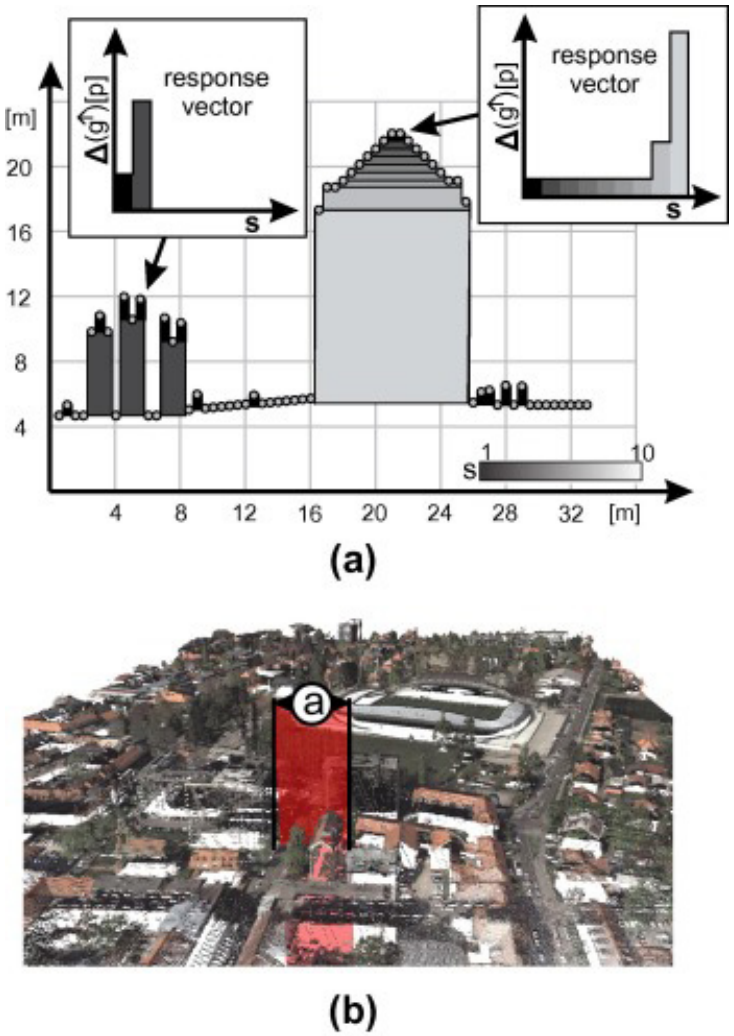



**Figure 4: Decomposition of a grid achieved by (a) progressive filtering of $g^{\uparrow}$ at increasing scales s, where a response vector $\Delta(g^{\uparrow})[p]$ is assigned to each grid-point, estimated from (b) the input LiDAR point-cloud. (Source: own)**

# Assessment and Optimization of Planning and Implementation of Tending Young Forest in Slovenia

## Financed by

ARRS – Slovenian Research Agency, MKGP RS (contract V4–1420)

## Duration

2014 to 2017

## Partners

UM Faculty of Electrical Engineering and Computer Science, UL Biotechnical faculty, The Slovenian Forestry Institute

The decrease in the realization of planned silvicultural treatment (tending) and concurrent increase of regeneration fellings may lead to a long-term decrease of quality and stability of the private and state forest and, at the same time, its capability to provide the ecosystem services. In the period 1993-2011, the realization of planned tending measures was around 58 %. The decrease of tending activities was especially pronounced in private forests, where only one-third of planned tending was implemented. This decrease is, on the one hand, a result of socio-economic changes and, on the other hand, a result of the decline in the state subsidies for tending. The decrease in the realization of tending measures could also be attributed to the prevalence of continuous cover silvicultural systems used in Slovenia, where education of young forest is done mostly by the appropriate canopy cover.

One of the demands connected to the Slovenian state and European Union subsidies for tending is a need to separate between tending for increasing the profitability of the forest and the tending that strengthens and preserves long-term ecosystem services of the forest.

This project aimed to review existing tending standards and to **develop a tending strategy**, especially for **damaged forests**, since in February 2014, almost 400.000 ha of Slovenia forests were damaged by an ice storm. Practical cases have shown that the damage caused by irresponsible salvage activities could be greater than the harm caused by the storm. During the salvage, it is important that we give special attention to fine-tuning of salvage logging and biological restoration, processes of secondary succession, setting priorities, and taking into account the recommendations of good practice in silviculture.

Our role in the project was to provide the needed support by the decisions about using natural regeneration versus planting in highly damaged younger stands. For that purpose, the secondary **succession model ForestMAS** has been used, which is based on Ellenberg ecological values. With the help of ForestMAS and its ability to interfere with the forest composition by generating clear-cuts and removing or planting individual trees, the regeneration of damaged areas could be studied and thus help to evaluate the tending models.

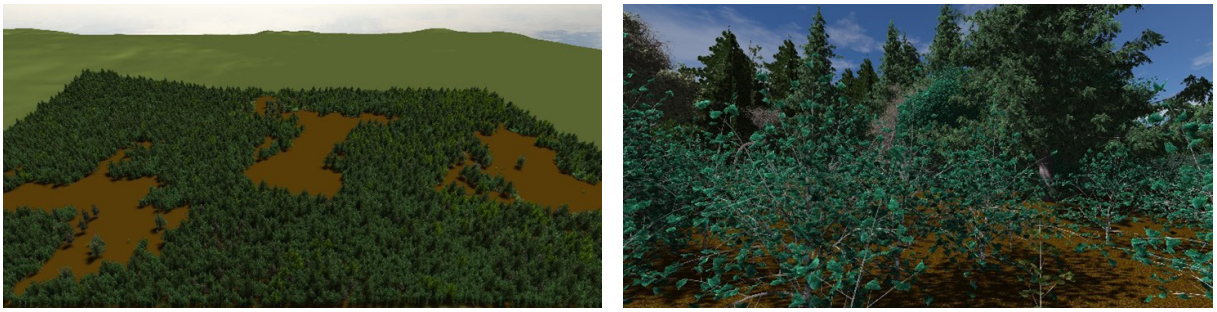


**Figure 5: Generating the clearcut regions (gaps) into dense forest countryside and the ground view of the regenerating area. (Source: own)**

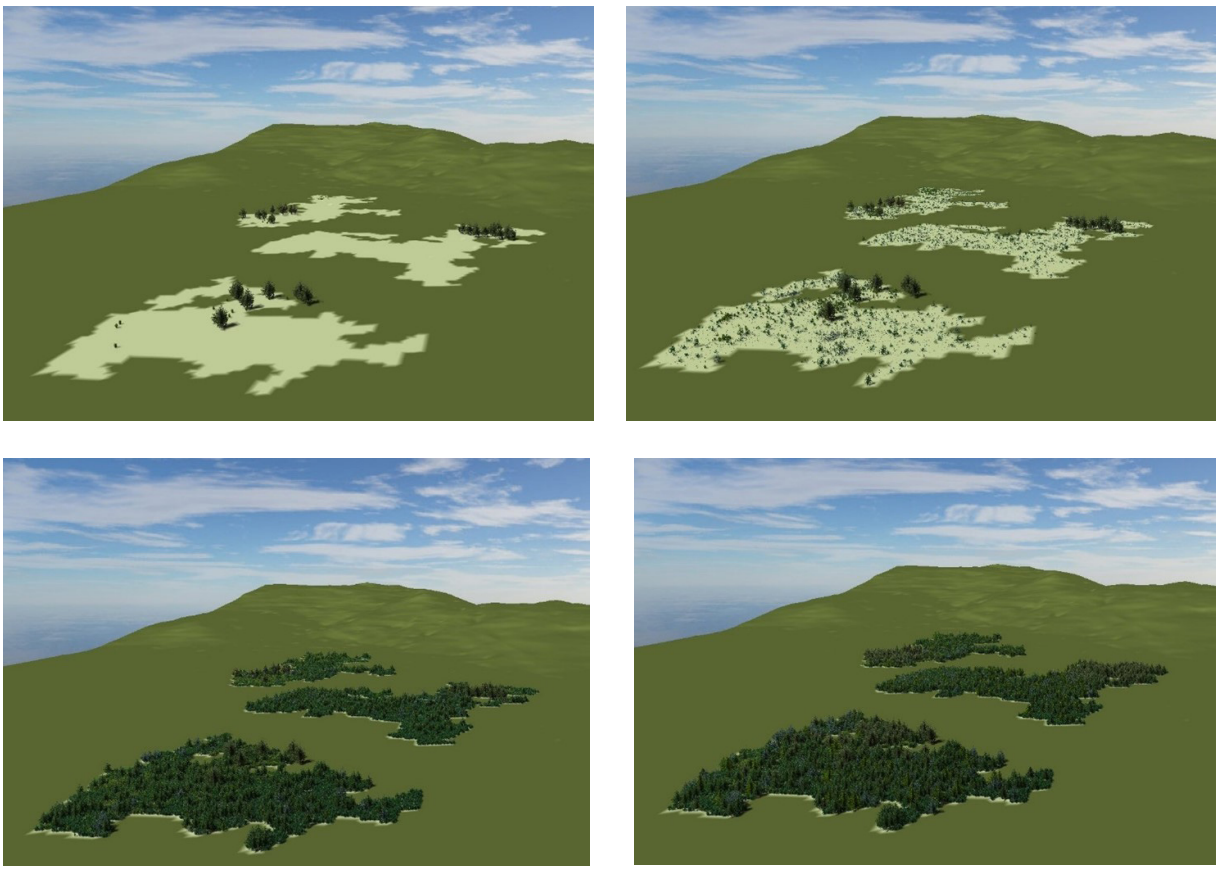


**Figure 6: Forest gap regeneration through 10, 30, and 50 years, respectively, depending on given seed trees. (Source: own)**

# Algorithms of Ecosystems Dynamics Modelling with Methods of Mathematical Morphology and Lattice Theory

## Financed by

ARRS – Slovenian Research Agency (contract J2–6764)

## Duration

2014 to 2017

## Partners

UM Faculty of Electrical Engineering and Computer Science, The Slovenian Forestry Institute

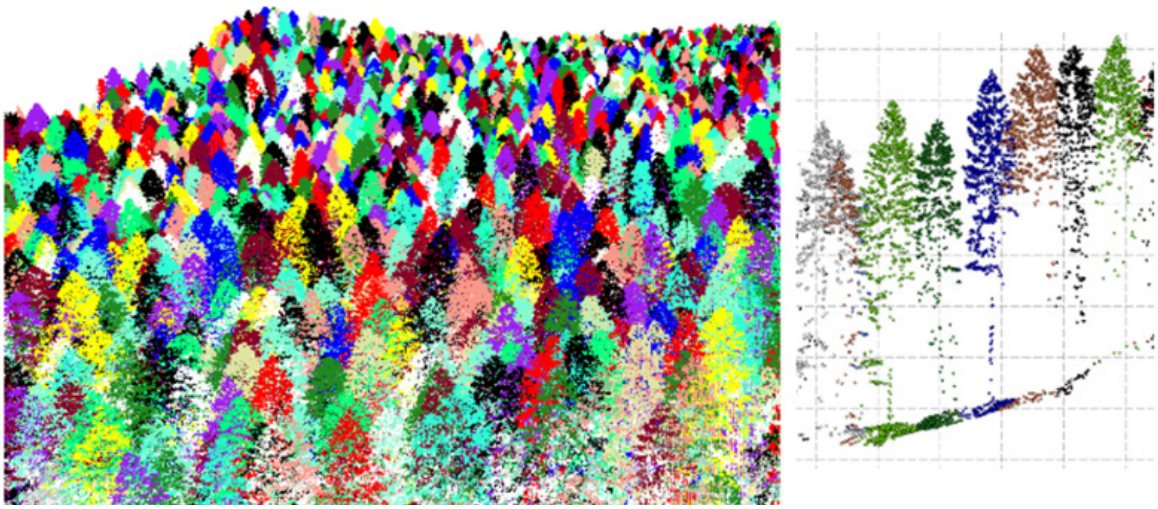
Sustainable management of the environment is a major challenge facing not only Slovenia, but also the entire mankind. Large ecosystems, especially forests, play a major role when addressing this task, having critical impact on the quality of life and obvious social-economic benefits for the society. Systematic and complete monitoring of the evolution of such ecosystems is extremely difficult, up to now even impossible, due to their vast geographic scales and huge amounts of their miniature basic elements. Only recent advances in remote sensing technologies that have revolutionized the area of Earth observations provide us with possible insights into the dynamics of such ecosystems. Sophisticated satellite observation systems from the Copernicus program and state-of-the-art laser scanning technologies like LiDAR, allow for periodical monitoring of large geographical areas with high enough resolution and precision to distinguish the smallest basic elements of ecosystems, such as trees, undergrowth, and shrubs. However, the huge amounts of heterogeneous and complex data they acquire remains a major challenge for the future as contemporary software solutions are incapable to deliver data analytics in a systematic, organized manner.

Before a holistic information space for efficient management of large ecosystems can be developed, major issues have to be addressed, regarding integration of heterogeneous Earth observations data, implementation of relevant analytic tools for their processing and, finally, relevant models of their dynamics.

The proposed project meets these challenges by introducing **a new paradigm for data integration** based on the decomposition of heterogeneous Earth observations into the contained basic semantic elements, their fusing and enrichment with complementary information from within different data types, and their inter-linking into a complex network. Through advanced concepts of mathematical morphology, formalizing arithmetic of shapes for sophisticated pattern analysis, the decomposition of specific data types and the recognition of the basic ecosystems' elements will be achieved. Their geometric features will be used to determine their social status, and consequently the likelihood of their mutual influence. These will be represented with a complex network, enabling us to develop a wide range of new algorithms based on up to now unexploited mathematical and analytical methods at such large scale. This new type of data analytics will be derived primarily from methodological studies of partially ordered sets based on lattice theory and statistical-topological features based on the theory of complex networks.

Such fundamental shift in the design of the pattern recognition algorithms will provide the thoughtfully required capabilities for the development of **new approaches to recognition of complex structures,** composed of multiple basic elements, while comparison of complex networks will allow for **systematic monitoring of their evolution**. Hence, the foundation for recognizing interactions between the basic elements will be established, giving us the framework for modelling dynamics of large ecosystems.

While in-situ measurements will be used to validate these algorithms, a study of forest dynamics due to the competition of trees for accessing resources and leaving space will provide the proof of concept. All the developed methods will be implemented in the form of weakly coupled service for this purpose and integrated into an existing platform for geographic data management and processing. A user-friendly environment for services orchestration and execution of analytic scenarios on-demand will be provided to experts in a form of end-user application.



**Fogure 7: Visualized LiDAR point cloud of a forest area decomposed to single trees. (Source: own)**

# InfraCloud – An Innovative Process for Creating Digital Models of Built-in Infrastructure Using a Cloud of Points

## Financed by

EU (ERDF); MIZŠ RS

## Duration

2016 to 2018

## Partners

UM Faculty of Electrical Engineering and Computer Science, CGS plus d.o.o., UM Faculty of Civil Engineering, Transportation Engineering and Architecture

## Additional information

**http://cgsplus.si/projekt-infracloud/**

GeMMA acted as an external contractor in this project. The aim was the development of semi-automatic algorithms for the recognition of built infrastructure and creation of virtual models for further design, reconstruction of built infrastructure or managing and maintaining infrastructure.

Accurate recognition of built infrastructure and the production of digital models enables integrated integral planning and management, and more efficient management and safer execution of interventions in the environment.

The application recognizes dominant points from input LiDAR data, defines built infrastructure element, and produces a digital model enriched with geometry and object attributes (BIM model). The model is then exported into open-source format in order to be exchanged with other software solutions.

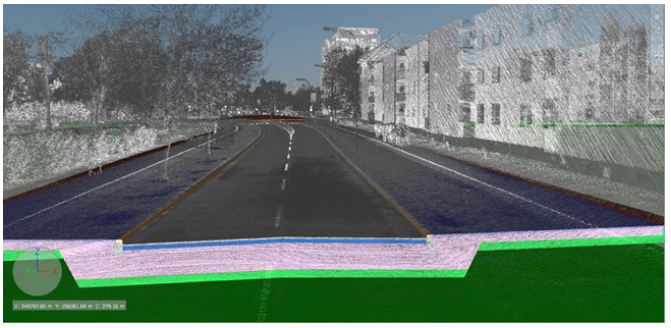


**Figure 8: Created digital enriched model of build infrastructure from LiDAR data with Infracloud. (Source: own)**



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# PAKT Architecture – IoT Based Machine Learning Model for Predicting Electricity Consumption

GeMMA acted as an external contractor in this project. The focus was on the analysis and machine learning architectures for predicting electricity production and consumption from real-time internet of things (IoT) data and, accordingly, balancing the electricity flows. For this purpose, extensive study of the existing technology for predicting electrical energy networks' workloads was conducted and key strongpoint and good practices were identified. Based on a technological solution for the use of machine learning methods in predicting electricity consumption and / or load on the electricity, the grid was designed at a conceptual level and tested in as a proof-of-concept.

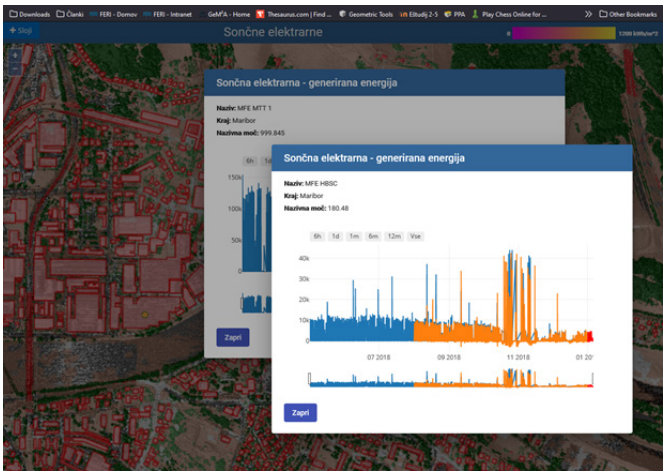


**Figure 9: Real-time energy production predictions in dedicated GIS. (Source: own)**

## Financed by

EU (ERDF); MGRT RS

## Duration

2016 to 2018

## Partners

UM Faculty of Electrical Engineering and Computer Science, Inea d.o.o., A1 Slovenija d.d., Borzen d.o.o., Elpros d.o.o., Geodetski zavod Celje d.o.o., Igea d.o.o., Iskraemeco d.d., Metronik d.o.o., Seltron d.o.o., Semantika d.o.o., Sipronika d.o.o.

# GOSTOP – Building Blocks, Tools and Systems for the Factories of the Future

## Financed by

EU (ERDF); MIZŠ RS

## Duration

2016 to 2020

## Partners

UM Faculty of Electrical Engineering and Computer Science, UL Faculty of Electrical Engineering, UL Faculty of Mechanical Engineering, UL Faculty of Computer and Information Science , Institute Jožef Štefan, TECOS, Kolektor d.o.o., Inea d.o.o., Metronik, Hidria Rotomatika d.o.o., Yaskawa Slovenija d.o.o., Podkrižnik d.o.o., Nela d.o.o., Cosylab d.d., L-TEK d.o.o., Špica international d.o.o., Optotek d.o.o., LPKF d.o.o., Fotona d.o.o.

## Additional information

**https://www.gostop.si/**

The aim of the proposed GOSTOP program was to accelerate the development of the **Factories of the Future concept** in Slovenia and to provide solutions to the current needs of Slovene industry, where some companies have already started to introduce this concept into their production facilities.

In GOSTOP, 13 companies and 6 research organizations with compatible research and development programs in the Factories of the Future area joined forces to advance the concept. Considering the **Smart Specialization Strategy of Slovenia** prepared by SVRK (Government Office for Development and European Cohesion Policy) and the priorities of the Factories of the Future roadmap under Horizon 2020 prepared by European Factories of the Future Research Association (EFFRA), we have identified 4 areas in which decisive breakthroughs can be achieved in Slovenia in the near future:

- **Control technologies;**
- **Tooling;**
- **Robotics;**
- **Photonics.**

This means that in GOSTOP we combined most of the horizontal fields pinpointed by the Smart Specialization Strategy of Slovenia documents for the Factories of the Future area. In all of these fields we determined the most promising research topics that are interesting for Slovene industry, where the necessary knowledge in Slovene research organizations exists and identified synergies between them. We combined several value chains in the program within which new products can be developed. This way, the competitiveness of Slovenian industry was improved significantly. On the one hand, GOSTOP includes the development of new products and breakthrough technologies by agile SMEs (small and medium-sized enterprise). On the other hand, we advanced the overall Factories of the Future concept, which lead to integrated systems that can be used by large Slovenian companies to optimize their production and develop new products with high added value.

An example of such a product included in GOSTOP is the **vision of a turnkey factory**. The success of GOSTOP has contributed to raising both the added value and the export volume of the participating companies and Slovenian industry at large.



GOSTOP Gradniki, orodja in sistemi za TOVARNE PRIHODNOSTI

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# EkoSmart – Eco System of the Smart City

EkoSmart addressed the **"Smart cities and communities"** priority subarea within the Slovenian Smart Specialisation Strategy (S4) priority area of **"Healthy working and living environment"**. It was selected for funding within the ERDF and MIZŠ RS public call (2016) for proposals "to support Research and development projects (TRL 3-6)".

The consortium of 12 innovative companies and 12 top research institutions was involved in EkoSmart implementation. The programme combined 6 interdisciplinary R&D projects (RDP1 to RDP6) in order to develop a smart city ecosystem with all support mechanisms needed for efficient, optimized and gradual integration of individual areas into a unified and coherent system of value chains. 4 RDPs focused on three key domains of smart cities:

- **Health (RDP4 and RDP5);**
- **Active living (RDP3);**
- **Mobility (RDP2).**

RDP1 introduced self-configurable, self-integrating, self-optimizing, flexible and adaptable universal smart city ecosystem architecture with capability of simple addition of modules, while RDP6 focused on development of prototype solutions and their testing in relevant environments.

**GeMMA** participated in work package WP4 ("Digital support, data, and acquisition of new knowledges") of RDP4 ("E-health and mobile health"), where it autonomously implemented two tasks – T2 (**"Machine learning Application for Discovering States of Illness and for Intelligent Support to Their Medical Treatment"**) and T3 (**"Enriching Medical Knowledge with Geographic Data"**).

Within T2, different machine learning approaches were analysed, and six of them were then integrated into innovative data mining tool. The selection consisted of neural networks, decision trees, clustering, support vector machines, linear regression, and random forest algorithm. The developed tool enables **iterative execution in multiple loops**.

## Financed by

EU (ERDF); MIZŠ RS

## Duration

2016 to 2019

## Partners

UM Faculty of Electrical Engineering and Computer Science, Marand d.o.o., Jožef Stefan Institute, URI-Soča, Špica d.d., UKC Ljubljana; UL Faculty of Electrical Engineering , UL Faculty of Computer and Information Science, Inova IT d.o.o., Elgoline d.o.o., Nela d.o.o., SRC d.o.o.; Cosilab d.d., ZD Adolfa Drolca, Iskra d.d, RC-IKTS d.o.o., Telekom Slovenije d.d., UL Faculty of Medicine, Robotina d.o.o., Alpineon d.o.o., UL Faculty of Sport, Klinika Golnik, Anton Trstenjak Institute of Gerontology and Intergenerational Relations, Medis d.o.o., National Institute of Public Health

## Additional information

**http://ekosmart.net/en/ekosmart-2/**

Typically, (hierarchical) clustering is performed in the early iterations, while the chosen attributes are predicted separately in each cluster later on. The tool also provides the **visualisation of multidimensional data module** for purposes of visual analytics. Within T3, the data analytics tool was upgraded with **geospatial and other georeferenced data** to provide functionalities of finding correlations between the medical and geographic attributes from heterogeneous data sources. The developed GIS extends the functionalities of visual analytics into the geospatial domain.

After the completion of RDP4.WP4.T2 and RDP4.WP4.T3 goals, GeMMA also participated in RDP6 (Solution prototypes), where the developed data analytics and visualisation subsystem was made ready for integration into the common EkoSmart ecosystem and validation in a relevant environment.


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# IQ DOM – Intelligent Home of a New Generation Based on Smart Devices and Wood

IQ HOME (SI IQ DOM) addressed the **"Smart buildings and homes, including wood chain"** priority subarea within the S4 priority area of "**Healthy working and living environment**". It was selected for funding within the ERDF and MIZŠ RS public call (2016) for proposals "to support Research and development projects (TRL 3-6)".

The consortium of 26 partners from various technological areas was involved in IQ HOME implementation. The programme combined 25 interdisciplinary R&D projects (RDP1 to RDP25) in order to provide advanced technological solutions implementing a new paradigm of an integral, green, mostly wood-based intelligent home adapted to resident's needs with extensive use of non-invasive artificial intelligence. Eight RDPs considered the building itself (the value chain of **"Advanced buildings with wood chain"**), 10 RDPs were devoted to devices (the **"Intelligent appliances"** value chain), while the remaining 7 addressed the value chain of **"Intelligent home management"**.

The overall goal was a transformation from an automated home to **self-learning adaptable home**. In such advanced home, users' behaviour is followed through inbuilt intelligent appliances, and artificial intelligence is utilized to mimic users' habits and thus simplify home management and additionally reduce energy consumption.

**GeMMA** participated in RDP5 – **Intelligent planning of constructions of buildings** (TRL 3-4, completed in the beginning of 2018). 3D models of several wooden-glass building modules were designed by UM FGPA and placed onto the tops of the models of selected real-world buildings in Maribor, and various analyses were then performed. GeMMA's role was to implement the activity **"Insolation analysis and optimisation of solar energy utilization"**.

The first step was to integrate detailed models of a wooden-glass module and a building upgraded with the module into the wider real-world environment model in a form of 2.5D grid constructed upon the classified LiDAR point cloud.

## Financed by

EU (ERDF); MIZŠ RS

## Duration

2016 to 2019

## Partners

UM Faculty of Electrical Engineering and Computer Science, Alples d.d., CBD d.o.o., Cosylab d.d., Elgoline d.o.o., INTECH-LES d.o.o., Kolektor group d.o.o., Lumar d.o.o., Robotina d.o.o., Roto d.o.o., Seltron d.o.o., SI.mobil d.d., Strip's d.o.o., Špica d.o.o., Institute Jožef Štefan, TECES, TERMO-TEHNIKA d.o.o., UP Università del Litorale Andrej Marušič Institute, UL Biotechnical faculty, UL Faculty of Civil and Geodetic Engineering, UL Faculty of Mechanical Engineering, UM Faculty of Energy Technology, UM Faculty of Civil Engineering, Transportation Engineering and Architecture, UM Faculty of Chemistry and Chemical Engineering in kemijsko tehnologijo, Lesarski grozd, wood industry cluster

## Additional information

**http://www.iq-home.si/en/**

Selection of the basic topological element is among crucial decisions prior to running the simulation and analysis of insolation. We have experimented on several geometric models (2.5D grid, voxels, triangle mesh), and finally accepted a hybrid model, where the wooden-glass module and the upgraded building are modelled by triangles while the environment was left in a form of 2.5D grid. We then adapted our photovoltaic potential estimation solution (pp. 35–37 in GeMMA 2000–2016 survey), but with an important difference that the original method only estimates suitability of buildings roofs for solar plants installation while the insolation analysis and optimisation performed in IQ HOME also require consideration of vertical surfaces, particularly those representing the walls of the wooden-glass module and the upgraded building.

Highly accurate estimation was achieved by considering the following factors:

- Long-term measurements of the direct and diffuse irradiance (for the period 2004–2015 with temporal resolution 15 minutes) provided by ARSO were utilized to calculate the so-called Typical Meteorological Year – TMY;
- Sun position simulation utilizes the algorithm published by the National Renewable Energy Laboratory (NREL), which computes the vertical and azimuth angle towards the Sun for a given micro-location at an arbitrary moment between years -2000 and 6000 with precision ±0.0003°;
- Self-shadowing and shadowing from surrounding obstacles (e.g. buildings and terrain) utilizes the computed Sun position and several geometric attributes of the 3D model;
- Shadowing from vegetation throughout the year uses satellite-based Leaf Area Index data;
- Finally, the time-based integration of calculated irradiance for a given time period considers all the factors mentioned above.

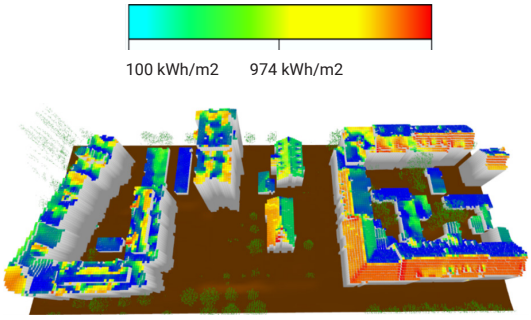
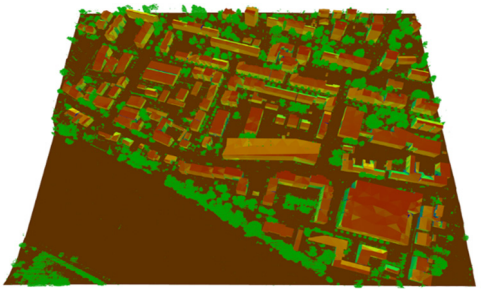



**Figure 10: Direct solar irradiance on roof surfaces in 2.5D grid. (Source: own)**



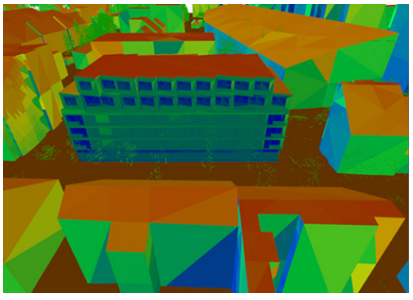


**Figure 11: Solar irradiance on vertical walls and roofs in triangle mesh model. (Source: own)**

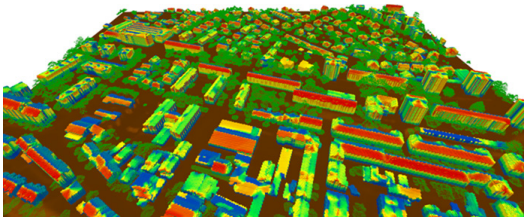


**Figure 12: Solar irradiance on vertical walls and roofs in voxel model. (Source: own)**



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# Crowdtrust – An Integrated Trust Model for Crowd-sensing Systems in the Context of Smart Cities

The project addresses the issue of involving residents in smart city systems using crowd-sensing systems. Crowd-sensing represents an important opportunity by actively involving residents (prosumers) in monitoring urban space and co-creating and improving urban infrastructure in a passive or active way. By integrating the population, we can significantly improve the quality of services, reduce the cost of investment in infrastructure and achieve measurable positive effects in improving the quality of smart city services. Despite the obvious advantages, there are a number of unresolved challenges in the field of crowd-sensing. The project focuses on two key ones. The first challenge is to ensure the highest possible level of trust in the data and information provided by people to the smart cities systesm. The ability to separate real data from untrue data and to eliminate the factor of human subjectivity is crucial. To this end, the first emphasis is on the development of an **original method for the identification and treatment of false data and the subjectivity factor in data captured in crowd-sensing smart city systems.**

## Financed by

EU (ERDF); MIZŠ RS

## Duration

2017 to 2020

## Partners

UM Faculty of Electrical Engineering and Computer Science, Inova IT d.o.o.,

The second challenge is the ability to **convince residents that the data they provide** is collected and processed exclusively for the purposes for which it is collected, that it **is stored in a way that prevents abuse or misuse and that an adequate level of trust is ensured**, which is an important prerequisite for the mass participation in crowd-sensing systems. The second focus of the project is on the development of innovative models and mechanisms for **secure and confidential storage and processing of crowd-sensing data** collected in a smart city environment based on block-chain technology and Ethereum platform, and the development of incentive mechanisms for participation in crowd-sensing environment. Both results are integrated into an integrated crowd-sensing trust model in the context of smart cities with support for two-way trust.

# PLACE – Predictive Analytics Based on Location-Associated Context Enrichment

## Financed by

ARRS – Slovenian Research Agency (contract J2–8176)

## Duration

2017 to 2020

## Partners

UM Faculty of Electrical Engineering and Computer Science, Geodetic Institute of Slovenia

Programmes like Copernicus, GEOSS, and Galileo, together with the Internet of Things enabled devices, are daily generating huge amounts of sensory data that are becoming widely accessible. This has resulted in an exponential growth of captured data, which is becoming increasingly more available and interoperable through open data initiatives (e.g. the Digital Single Market of the EC), open source software (such as GeoServer), and open standards (e.g. the OGC and INSPIRE Directives). These not only provide us with the opportunity to observe the natural processes at high spatiotemporal resolution, but also enable us to monitor the causal relationships that are driving them. Although contemporary methods are capable of aligning geospatial data from different information layers, assessing semantic features in a single or few aligned layers, and analysing raw data and/or extracted features, they often remain restricted to selected data types (e.g. hyperspectral and LiDAR or sensors connected through wireless networks), where the integration of domainspecific knowledge is relatively straightforward. Moreover, they do not incorporate data enrichment sufficiently, causing much of the data to be underexploited.

As a result, many current state-of the-art methods are only capable of targeting situation assessment, while impact assessment is a characteristic of only a few domain specific decision support systems, where the contextual information is administered by users. Due to the complexity of interactions within and amongst natural processes and their relations to human activities, extraction of this so-called contextual information has only now become possible.

In the PLACE (Predictive analytics based on Location-Associated Context Enrichment) project, we addressed contemporary challenges of structured context representation within the fusion of heterogeneous geospatial data sources and streams. For this purpose, we first acquired the context based on the development of temporal-spatial analyses using the concepts of computer geometry, topology and geospatial statistics, thus presenting **new approaches to the recognition of contextual relationships** and their structured presentation. Subsequently, we used context in predictive analyses, developing **new methodologies for integrating structured contextual information** to improve the accuracy of currently known methods of environmental simulations and regression models. The PLACE data fusion approach resembles a spiral model, capable of achieving **"self-enrichment" of data** during few iterations through the supporting processes. The latter include definition of geospatial entities (or objects), feature extraction, context structuring, and predictive analytics.

Research activities were placed in two validation scenarios:

1. Prediction of microclimatic parameters, where we concentrated mainly to wind potential, heat load of buildings and air pollution.
2. Prediction of geomorphological changes, where we concentrated mainly to the study of glaciation or geomorphological changes due to the movement of frozen water – ice.

The research results were published in prestigious scientific journals, where 17 papers were published in journals with SCI. Among them, 12 are in the A' according to the Slovene research agency classifications, and 5 in A". In order to internationally promote the achievements of the project, 9 conference papers have been published. An patent was granted to us, too, that successfully passed a patent test in the United States. In this way, the research aims were outdone.

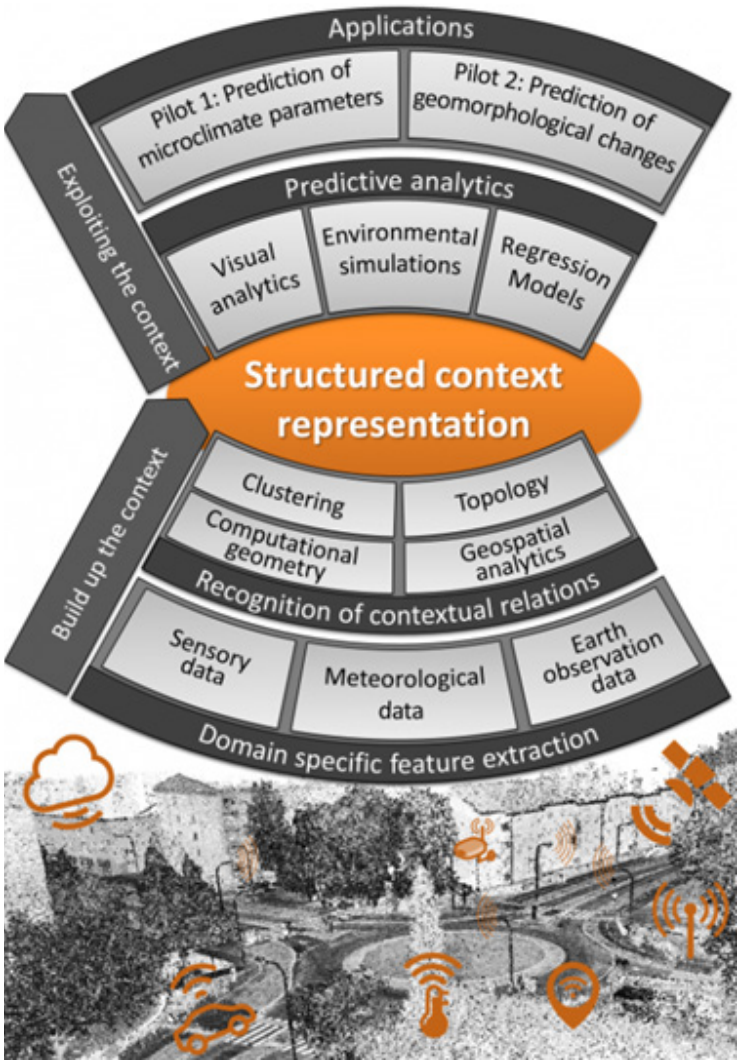


**Figure 13: Predictive analytics system arhitecture for achieving location associated context enrichment. (Source: own)**

# WIBRANT – Wearable Integrated Smart Brace for Rehabilitation Monitoring and Diagnostic of Disorders in Muscular Functions

## Financed by

EU (ERDF); MIZŠ RS

## Duration

2018 to 2021

## Partners

UM Faculty of Electrical Engineering and Computer Science, Skylabs d.o.o., Inova IT d.o.o., Institute for Sports Medicine at UM Faculty of Medicine

## Additional information

https://www.skylabs.si/wibrant/

WIBRANT addresses the **"Healthy and active aging"** priority subarea within the S4 priority area of **"Health – medicine"**. It was selected for funding within the ERDF and MIZŠ RS public call (2018) for proposals "to support Research and development projects (TRL 3-6)". Its main goal is to develop a cutting-edge **wearable sensory system** in a form of an easy to wear smart flexible brace that enable **improved tele-diagnostics and tele-rehabilitation of muscular disorders**, while also making these services affordable to elderly people.

The holistic solution provided by WIBRANT technology consist of the following innovative components that was realized in the **Phase 1 (TRL 3-4)** of the project:

- Carrier Brace Textile represents a comfortable wearable smart material, suitable for integration of the sensory system;
- Integrated flexible electronic sensory system (miniaturized microcontroller unit with memory and peripherals – sensors) perform energy-efficient patient monitoring in a real-world environment and provide local data storage, data pre-processing capacities, and data transfer to mobile devices;
- Mobile application provides efficient data transmission services interface between wearable electronics and its data storage on one side and the processing server. Besides this, it enables patients to monitor their rehabilitation progress;
- Data analytics platform is data storage and management capacities that enable doctors to monitor the rehabilitation processes of their patients with dedicated advanced services for the assessment of musculoskeletal functions and treatment assignment. Furthermore, they get an in-depth view into the environmental parameters that influence the patient's rehabilitation outside of the laboratory environment.

**Phase 2 (TRL 5-6)** – here, the focus was on the completion of technology validation and technology demonstration in a relevant environment. For this purpose, a pilot environment was set-up at ISM. During these technology demonstration activities, involvement of potential customers (e.g. University Medical Centre Maribor) was conducted, while the first push towards integration into the global chain of values was made in partnership with Adidas, which strongly supports the project.

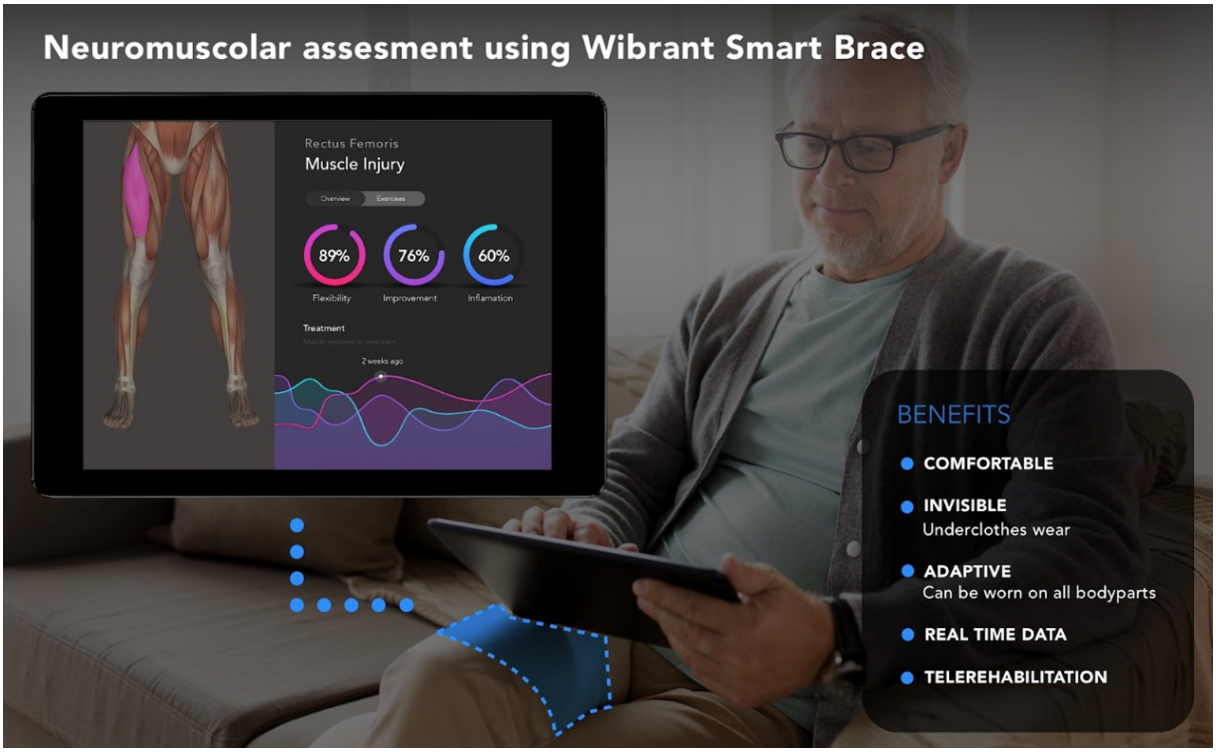


**Figure 14: The envisioned design and application of the Wibrant Brace (Source: WIBRANT project proposal).**

The WIBRANT consortium joined leading experts from diverse technological fields in order to successfully design and implement all these distinct but complementary subsystems. FERI MS was competent for smart textile design, while Skylabs has utilized its nanoelectronics expertise to develop the sensory system, and Inova IT was responsible for the mobile application and data transmission. GeMMA has used its expertise in spatiotemporal data analytics and provided advanced algorithms for fusion of sensory information with geospatial data (e.g. temperature, water moisture, and patient tracking data) and for machine learning algorithms for pattern recognition aimed to extract casual relationships between the sensory measurements and environmental data.

After the completion of the project, the following main contributions of GeMMa were:

- In addition to the consortium's support with existing data analysis techniques, GeMMA's researchers provided a new approach that transforms raw input data from Wibrant Smart Brace into geometrical deformations of the brace. Besides that, GeMMA also successfully introduced a new algorithm that maps deformations into a tensiomyography data;
- A new method for visualization of geometrical deformations of the smart brace was created;
- Simulation of muscle deformation with motion capture system was successfully conducted;
- A new iterative approach to explainable feature learning was introduced;
- Two journal articles listed below and one patent application which describes an apparatus and a process for real-time monitoring of deformation of smart elastic textiles based on measurements of electromagnetic characteristics were proposed.

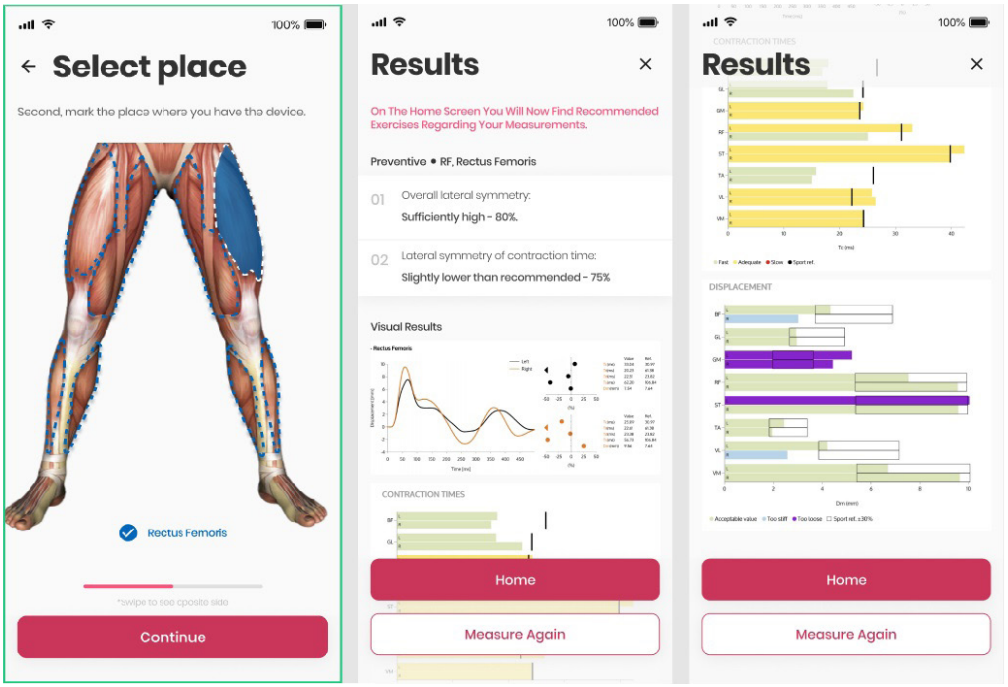


**Figure 15: Wibrant mobile application for monitoring muscle activities. (Source: own)**


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# ION – Integration of Indoor and Outdoor Navigation

ION addresses the **"Mobility, transport and logistics"** priority subarea within the S4 priority area of **"Smart Cities and Technologies"**. It was selected for funding within the ERDF and MIZŠ RS public call (2018) for proposals "to support Research and development projects (TRL 3-6)".

Its main goal is a **personalized navigation system** aimed to provide integrated indoor and outdoor routing services, particularly adjusted to **support people with mobility impairments**. This objective was achieved in the first ION phase (TRL 3-4) by developing:

- A new software solution, providing generation of enriched navigation maps with mobility parameters and restrictions such as stairways, width and height of sidewalks, routes' steepness, location of elevators and ramps for individuals with mobility impairments by extending on the existing OpenStreetMap data models and providing advanced spatial data editor with ability to edit geometry and attributes directly in the spatial database;
- A new indoor positioning system based on visual light communication (VLC) and compliant with mobile devices i.e. relying on existing mobile light detection sensors and existing infrastructure geometry descriptions;
- Next generation navigation platform capable of mapping indoor and outdoor coordinates to the common coordinate system and switching between indoor and outdoor positioning, while considering personalized preferences for optimal path finding via dynamic path attribute filtering and rule evaluation engine.

### Financed by

EU (ERDF); MIZŠ RS

### Duration

2018 to 2021

### Partners

UM Faculty of Electrical Engineering and Computer Science, Inova IT d.o.o., Astron d.o.o., UM Faculty of Civil Engineering, Transportation Engineering and Architecture

### Additional information

**https://ion.inova.si/sl.html**

Within the second, pilot phase (TRL 5-6), the ION prototype platform was tested and validated in the selected real testing environments, set-up within bounds of the Municipality of Maribor and in one of the SPAR's markets.

**GeMMA** with its expertise in geospatial data processing algorithms and platforms development participated in ION by providing the back-end server-side infrastructure and services for navigation, enriched outdoor navigation map generation software, advanced graph-based path finding algorithm, collision detection, and indoor-outdoor coordinate matching. INOVA IT was responsible for front-end mobile applications, and ASTRON's expertise in advanced electronics which they utilized for VLC electronics components, while FGPA's in-depth knowledge and understanding of urban mobility challenges were of indispensable value for technology steering, consolidation of user requirements and technology validation, and for communication with potential customers and end-user communities.

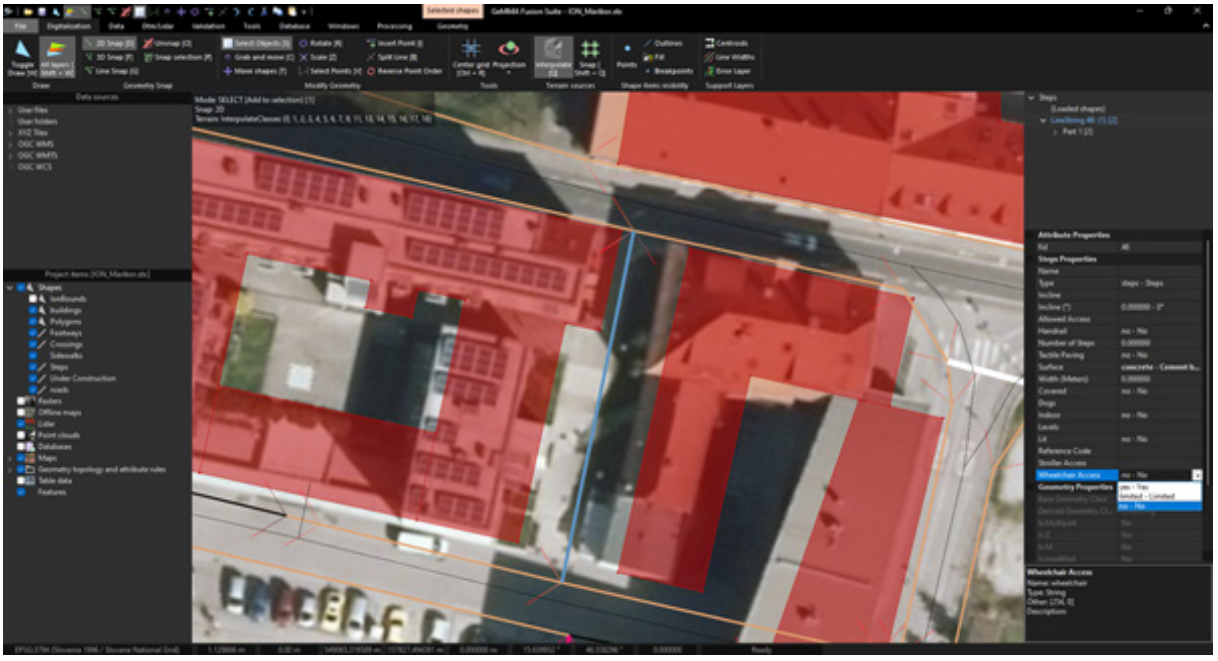

**Figure 16: Editing experience of the standardized spatial data with attribute schemas for easier information input. (Source: own)**

**Figure 17: Visualization of the spatial graph streamed directly from the database which is used in pathfinding engine to provide detailed multipoint navigation for multiple transportation types with personalized rules. (Source: own)**



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# IPOT – An Integrated Pilot Environment for Sustainable Smart City Mobility

**GeMMA** is participating in the project as an external contractor providing the technological backbone with integrated data fusion and back-office analytics for the following applications. The purpose of the iPOT project is to establish and integrate a **next-generation mobility platform** into the demonstration environment, which primarily, as a unique product on a global scale, enables the collection and processing of large amounts of data in real time. The project covers the field of **mobility, transport, logistics**, the key goal of which is to increase the mobility of people and goods by providing reliable, flexible, accessible, safer, and green urban and suburban services. The development of the modules is currently running in the direction of **increased security in car parks**, which aims to strengthen security in smart cities in both public and private sector. We are also directly involved in the field of quality of urban living, the key goal of which is to raise the quality of life in urban environments by ensuring **sustainable green economic and social development**.

The key objectives of the project are:

- Establishment of a **traffic control room;**
- Implementation of **dynamic traffic regimes;**
- **Smart parking;**
- **Integrated payment** for mobility services.

### Financed by

EU (ERDF); MGRT RS

### Duration

2019 to 2023

### Partners

UM Faculty of Electrical Engineering and Computer Science, Iskra d.o.o., A1, Comtrade, Globtel holding, Žejn group, Igea d.o.o., MSG Life, BAS5, Inova IT d.o.o., Spark d.o.o.

### Additional information

**https://ipot.si/**

Due to its modularity, the iPOT solution is the foundation for effective global planning of other models of sustainable mobility in various urban agglomerations around the world.

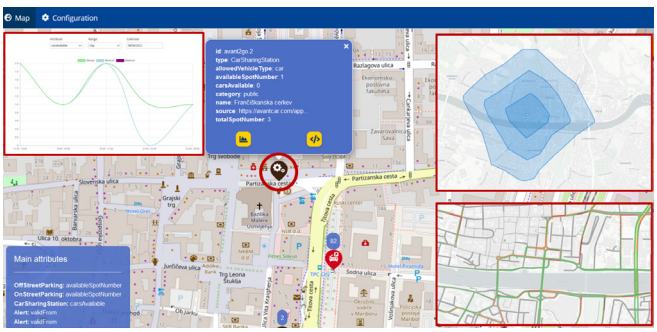



**Figure 18: IPot car sharing control applications. (Source: own)**

# Energy Management System for Electric Devices

## Financed by

ARRS – Slovenian Research Agency (contract J2–1742)

## Duration

2019 to 2022

## Additional information

**https://ime.feri.um.si/energetika/raziskovanje/projekti/sistem-za-upravljanje-z-energijo-elektri%C4%8Dnih-naprav**

This was an ARRS basic research project lead by **Laboratory for power engineering** at UM FERI, where GEMMA was a collaborating research partner. The main goal of this project was to **develop and validate a new concept of EMS**. The developed energy management system eliminates most of the mentioned shortcomings. In order to achieve the goal of the project, the following tasks have been performed:

- To provide information that is essential for decision-making, automated modelling of individual devices (generating units, storage tanks and energy consumers). The process was based on machine learning. It enabled automated creation and adaptation of device models based on measurements during normal operating states of devices. Developed device models were implemented centrally on EMS or locally on switches / meters. When necessary, the EMS was able to use the model to estimate the values of the observed variables at the time the action is performed before actually performing that action. These models supported the EMS in selecting the best measures.
- A new EMS autonomous decision-making algorithm (AAO) was introduced to mimic market behaviour. The decisions of the AAO EMS were based on assessments of the condition of individual units for the production, storage and use of energy, which were provided by the models of these devices. Such an AAO EMS, based on an analysis of the situation and supply or demand of the aggregator, was able to accept or reject the offer, and at the same time was able to offer or demand services. The existing transmission of requests to users regarding the switching on and off of their devices was replaced by the exchange of supply and demand between AAO EMS and the aggregator.
- An experimental EMS testing system was be set up to validate the proposed concept. It included controlled generation units (PV systems with micro-converters), energy storage (SCiB battery system and converter) and consumer devices (refrigerator, water heater, several air conditioners and other energy consumers). The experimental system was used to test the automated generation of device models, their ongoing adaptation, testing the properties of the developed EMS in parallel and island operation. It was also used to verify the suitability of the developed AAO EMS.

**Figure 19: Existing Experimental system at Laboratory for power engineering, UM FERI.**
**(Source: https://ime.feri.um.si/energetika/raziskovanje/projekti/sistem-za-upravljanje-z-energijo-elektri%C4%8Dnih-naprav).**

# LiDAR-facilitated Volunteered Geographic Information for Topographic Change Detection


## Financed by

ARRS – Slovenian Research Agency (contract J2–1742)

## Duration

2019 to 2022

## Aditional information

**https://ime.feri.um.si/energetika/raziskovanje/projekti/sistem-za-upravljanje-z-energijo-elektri%C4%8Dnih-naprav**


Acquisition of volunteered geographic information (VGI) or geographic crowdsourcing has gained increased attention from academia in the last decade, especially for topographic change detection, collaborative mapping and natural hazard monitoring. By means of VGI we can collect positional data and georeferenced text, messages, photos or other information, e.g. by tagging existing information with geographical location.

Different approaches can be used to motivate citizens and professionals to participate in VGI, while the main motivation is usually a desire to cooperate in a worthy cause. Better data quality can be achieved if, together with laymen as data contributors, experts are cooperating.

Topographic maps and data cover entire states. In the A4C4 quality requirements scheme (Authority, Accuracy, Availability, Actuality, Completeness, Coverage, Consistency, Correctness), VGI wins in comparison with expert topographic data only in Actuality and conditionally in Correctness, but this is very significant for the Surveying and Mapping Authorities (SMAs).

European SMAs renew topographic data periodically, e.g. once in every 3 years. In order to achieve high and geographically homogeneous Actuality of VGI input at any time (i.e. continuously), SMAs have to attract data contributors all over their countries. Therefore, the main goals of this research are:

1. **To empower volunteers for easy and quick data collection;**
2. **To empower geodetic professionals to process these data with photogrammetric quality.**

A term facilitated volunteered geographic information was introduced, which describes the fact that the collection of VGI can be accelerated if the beneficial institution like SMA, supports volunteers e.g. with simple and user-friendly applications such as digital mapping interfaces or topographic data browsers.

When VGI, especially volunteered photos are crossed with complementary georeferenced big data, e.g. with LiDAR point clouds or photogrammetrically derived digital surface models (LiDAR-like data) of whole countries or satellite images, new research directions emerge. Given the potentials offered by VGI and volunteered photos collection, the following three beyond state-of-the-art research problems arise:

**CENTRAL PROBLEM** – How to optimize the methodology of topographic map updating to involve arbitrary VGI, single volunteered non-metric photos, LiDAR or LiDAR-like data and satellite images?

**CONTEXTUAL PROBLEM** – How to support volunteers in the facilitated VGI, and in the volunteered non-metric photo collection for the purpose of full quality photogrammetric map updating:

1. For different topographical changes e.g. of road network, buildings, land use and land cover;
2. At different national topographic map scales of e.g. 1:5000 vs. 1:50.000.

**TECHNOLOGICAL PROBLEM** – Specifically:

1. How to photogrammetrically orientate and georeference a single non-metric volunteered photo made by amateur camera or mobile phone;
2. how to extract and map 3D topographic changes from such an amateur photo only with the help of LiDAR or LiDAR-like data.

Topographic map updating is usually done by photogrammetric survey, where imagery used to detect changes is professional, i.e. metric, orientated, stereo (in pair), and vertical (aerial - from an airplane). The main objective of the proposed research is the development of **optimal methodology for a topographic map updating** based on a mashup of volunteered geographic data, volunteered amateur photos and professional LiDAR or LiDAR-like data. We can summarize this with the following hypothesis:

**A topographic mashup of arbitrary VGI, volunteered photos, professional LiDAR or LiDAR-like data and/or satellite images can provide a professional standard quality input for 3D topographic change detection and mapping in the process of topographic map updating.**

# EKOGEN – Economics of Farming with the Support of Geospatial Analyses

## Financed by

EU (ERDF); MGRT RS

## Duration

2020 to 2022

## Partners

UM Faculty of Electrical Engineering and Computer Science, FlawlessCode d.o.o., Igea d.o.o., ITC Murska Sobota

## Additional information

**https://flawless-code.com/ekogen/**

EKOGEN addresses the issue of small farm economics by developing an advanced tool to support **on-farm production planning**. Because we are aware of the limited capabilities of small farms to reach out for advanced precision farming technologies, we limit our scope to the agricultural advisors, who we see as the bearers of digitization processes.

The developed products enable them to systematically plan production for their customers (farmers), and primarily consists of:

- Development of **tools for visual modelling of production** and definition of agricultural scenarios, which enables the integration of open data sources for geospatial planning of crops and monitoring their development;
- Upgrades to the existing expert system of **economic calculations** for the validation of specific scenarios, assessment of related costs and risks and potential sales revenues;
- Adaptation of services for visual analysis and reporting, which enables the **optimization of scenarios** and generation of **reports for third parties** (banks, insurance companies, …) with methods of the artificial intelligence.

The project was based on an existing market product, which is in use today by Slovenian consultants, which we further upgraded to a market product with a global reach. In the context of S4, the project addressed the priority area of **"Sustainable Food Production"**, within which it focused on the area of **"Smart Process Planning and Process Control"**.

As an external contractor with the expertise on the geographic information systems our role was to develop advanced tools for geospatial data processing and establish development infrastructure that allows project partners to collaborate on the development process by integrating developed applications and services in the common environment.

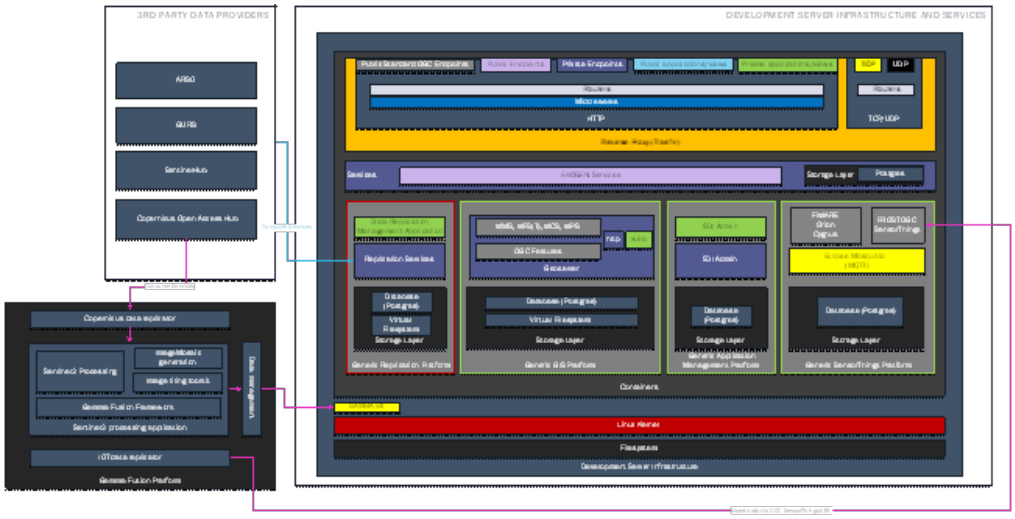



**Figure 20: Development infrastructure for geoprocessing of the Sentinel-2 data and developed services. (Source: own)**

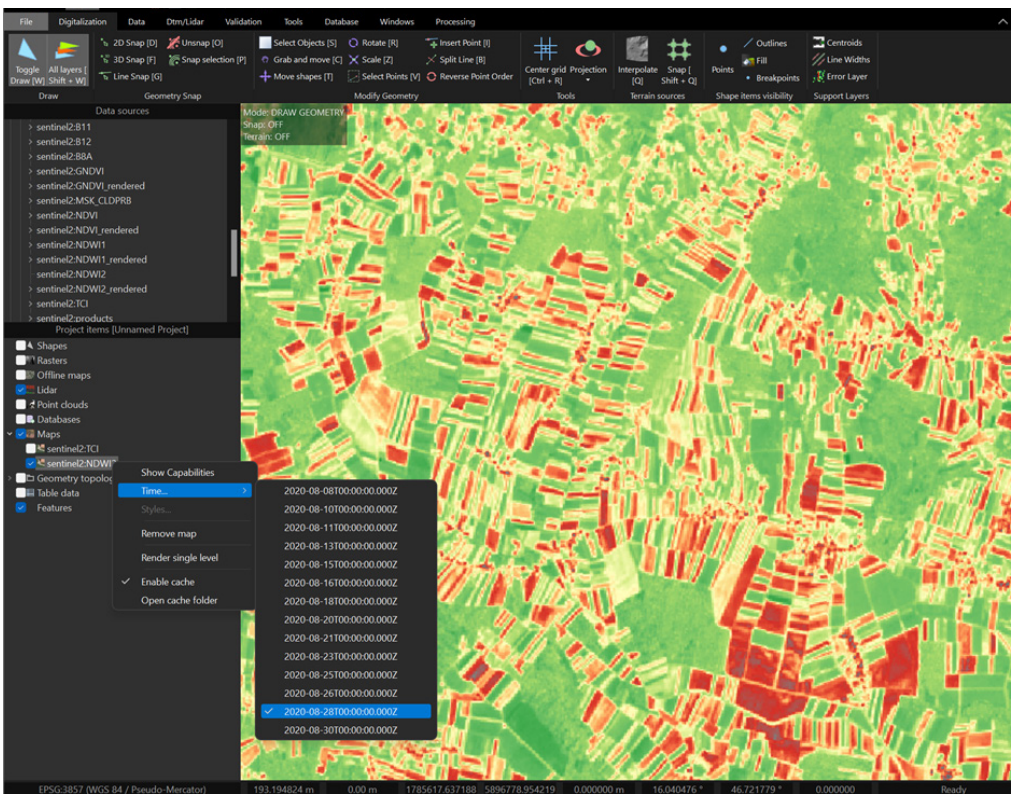



**Figure 21: Visualization of the generated Sentinel-2 products. (Source: own)**

# Implementing Digital Twins of Ecosystems of Agricultural Lands

## Financed by

ARRS – Slovenian Research Agency (contract L7–2633)

## Duration

2020 to 2023

## Partners

UM Faculty of Electrical Engineering and Computer Science, Igea d.o.o., KGZS Murska Sobota

Digital twins have become a major technology trend and a critical component in the implementation of smart environments. With their ability to mimic the behaviour of real-world entities in virtual environments, they provide advanced monitoring, diagnostics, prognostics, and optimization capacities. However, as their implementation requires convergence of many technologies and non-technical aspects, ranging from Internet of-things to artificial Intelligence with integrated domain-specific knowledge, their usage today is limited to highly controlled environments, such as smart factories and smart homes. Their immense potentials to provide environmental intelligence, thus, remain unutilised, specially, when considering protection of Earth from degradation through sustainable management of its natural resources and urgent actions against climate changes.

Today, food production is amongst the main producers of greenhouse gases (GHG), while being under immense pressure due to the rapid urbanisation. It is, therefore, critical to address the trade-off between safeguarding food production, while lowering GHG emissions. This can only be achieved by deepening understanding of our interactions with agricultural ecosystems.

The proposed project addresses contemporary challenges of digital twins for modelling such socio- environmental interactions by providing significant advances beyond state-of-the-art in the following aspects:

- A new in-situ , capable of simultaneously capturing **CO2, N2O and CH4 emissions**, together with **temperature** and **moisture** of surroundings as well as levels of plant photosynthesis using **quantum sensor** with location data provided by Galileo;
- A **data harvesting system,** intended for gathering and aligning IDEAL's in-situ data with open Earth observation data sources (e.g. Copernicus satellite images, GEOSS thematic maps, and LiDAR data from Slovenian environmental agency) for common representation of spatiotemporal entities;
- An **advanced data fusion framework** designed for mining IDEAL's data sources by the principles of deep and feature learning for **spatiotemporal extrapolations and crop-growth simulations**;
- Process **optimization and visual analytics services** for providing for prescriptive analytics capacities of socio-environmental interactions with the support of explainable artificial intelligence.

As a result, IDEAL digital twin shall enable:

- Farmers' interaction with agricultural ecosystems;
- Of green-house-gas emissions, soil health, and crop development parameters;
- Of their changes during the time;
- Optimization of farming processes, accordingly.

In accordance with user-centric design, project development shall be governed by three complementary pilots, each addressing the specifics of a particular agricultural ecosystem that all together cover 98% of Slovenian farmland, namely, grasslands, arable lands, and permanent crops.

Within each of the pilots, systematic data collections shall be conducted periodically during crop and grass growth, before and after all major farming activities, including tillage, fertilization, planting, and harvesting in order to ensure accurate profiling of the following parameters:

- **High-resolution GHG emission that includes carbon dioxide (CO2), nitrous oxide (N2O) and methane (CH4);**
- **Soil health parameters and derived nutrition levels, as for example fertility indices, pH, and manganese;**
- **Crop and grass development parameters based on their physical features like levels of photosynthesis productions and growth.**

In order to maximize the project potentials, IDEAL digital twin shall be plugged-in into existing precision farming infrastructure provided by industrial partner (namely Igea d.o.o.), turning natural ecosystem into a smart environment. IDEAL shall, thus, provide the necessary social innovation infrastructure to the researchers and practitioners that are currently struggling with low level of general digitalization in agricultural sector.

# Landscape Heterogeneity and the Forthcoming Agricultural Policy Measures in Slovenia

## Financed by

ARRS – Slovenian Research Agency, MKGP RS (contract V4–2018)

## Duration

2020 to 2022

## Partners

UM Faculty of Electrical Engineering and Computer Science, UM Faculty of Arts, UM Faculty of Natural Sciences and Mathematics, Geodetic Institution Celje

The problem of biodiversity loss due to intensified agriculture and abandonment of high nature value farmland has been recognized as one of the major environmental problems in the European Union. Slovenia is trying to contribute to landscape biodiversity conservation through agricultural and other policy mechanisms, which include landscape features as crucial biodiversity elements of its mosaic landscape. The aim of this project is to contribute to the **re-definition of agricultural landscapes in Slovenia**, and define the measures to improve the current situation with landscape features through the following goals:

- Identify areas for the conservation, restoration and establishment of landscape features, and the definition of a set of landscape features suitable for the conservation of biodiversity in agriculture;
- Prepare recommendations for the appropriate management (conservation, restoration and establishment) of individual landscape features;
- Prepare a classification and precise definition of landscape features relevant to both biodiversity and agriculture, and identify those landscape features that need to be maintained at the level of conditionality and those that should be maintained through climate and environmental schemes;
- Define the dividing line between standard and above-standard measures, and prepare appropriate calculations for support for farmers;
- Prepare the contents of mandatory and above-standard measures with a clear intervention logic, and propose an appropriate minimum share of agricultural area intended for non-production characteristics or landscape features;
- Prepare starting points for determining the landscape features for inclusion among the eligible areas of income support under the direct payment scheme;
- Develop an appropriate system for capturing data of individual types of landscape features in order to improve the databases;
- Prepare an upgrade of the existing inventory of landscape features, adapted to the needs of the Ministry of Agriculture, Forestry and Food for the needs of preparation and effective implementation of the Strategic Plan from 2023 onwards, which will be suitable for inclusion in the Land Parcel Identification System (LPIS), and preparation of its maintenance proposal.

The two main activities of GeMMA within the project are the development of spatial support information system for conservation of landscape features, and the testing of algorithm for landscape feature identification from available satellite, orthophoto, LiDAR and other spatial data for the selected area.


**Figure 22: Application for monitoring and planning of landscape features. (Source: own)**

# Generalized Symmetries and Equivalences of Geometric Data


## Financed by

ARRS – Slovenian Research Agency (contract N2–0181)

## Duration

2021 to 2023

## Partners

UM Faculty of Electrical Engineering and Computer Science, University of West Bohemia (UWB) in Pilsen, Czech Republic


An object has symmetry if there is a transformation (such as rotation, translation, scaling, reflection, etc.) that maps it onto itself. Being symmetric is a potentially very useful feature. Symmetries in the natural world have often inspired people to incorporate them when producing tools, buildings, artwork etc. Therefore, it is important to be able to detect symmetries in geometric data. Consequently, symmetry detection became a challenging research topic particularly in pattern recognition, computer vision, computer graphics, and geometric modelling, where it addresses problems such as object alignment, data compression, symmetrical editing, reconstruction of incomplete objects, or technical illustrations support.

In the GeoSym project, three complementary groups of researchers decided to join their efforts, knowledge and experience to address the most current symmetry-related challenges:

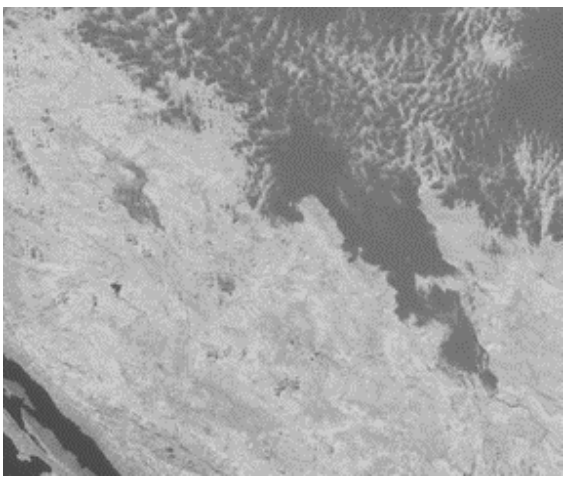
- The computer graphics group from UWB: knowledge and ambitions in the development and implementation of geometric algorithms;
- The group of mathematicians from UWB: study of formalized and generalized concepts in geometry and geometric algorithms;
- The group from GeMMA at UM FERI: expert knowledge in EO data processing.

Based on the previous research activities of all three groups and the identified symmetry-related challenges, the following research objectives were set:

- Development of fast and reliable methods for detection of generalized symmetries, considering global, local, reflectional, rotational (axial), perfect and approximate symmetries, for common as well as highly non-uniformly distributed or perturbed input point sets and for continuous curves/surfaces;
- Development of new methods for detection and computation of exact projective equivalences for finite sets of points (solutions of polynomial systems) and for further special algebraic varieties (mainly 3D surfaces), and of approximate equivalences and symmetries of perturbed objects;
- Integration of symmetry detection into the methodology of semantic segmentation and object recognition in EO data in order to improve accuracy and enlarge the set of recognized classes, validated in a dedicated set of applications.

Both participating universities will benefit from the cooperation. The Czech researchers receive a valuable feedback on how their existing and planned methods of detecting generalized symmetries will cope with the peculiarities of huge, noisy, incomplete, and unevenly distributed real data. On the other hand, the Slovenian researchers expect that the new symmetry-aware features will further improve their EO data fusion methodology, which already successfully classifies points of ground, buildings, and vegetation. Thus, some selected subclasses of buildings are expected to be identified, and the first steps towards the identification of tree species are also planned.

a)



b)

**Figure 23: a) Sentinel-2 satellite image of Northern Dalmatia with hinterland and b) best of the detected reflectional symmetries. (Source: own)**

In the first year of the project, GeMMA team provided a repertoire of EO datasets, representing separate buildings and trees extracted from pre-classified LiDAR, and the Czech side then performed tests of their own global reflectional symmetry detection algorithm. At the same time, GeMMA tested the same algorithm on EO raster (Sentinel-2) data. After that, the software framework has been developed to provide functionalities of reading EO data of diverse types, symmetry detection in this data, integration of detected symmetries into the feature extraction and data fusion, e.g. classification, segmentation, object recognition, as well as the visualization of input data and results. The GeMMA Fusion Suite software development kit (GFS SDK) was adapted for this purpose. Furthermore, GeMMA has also developed and implemented a couple of novel algorithms for global and local reflectional symmetry detection adapted to EO data, while the algorithm for rotational symmetry detection is about to be finished till the end of 2022.

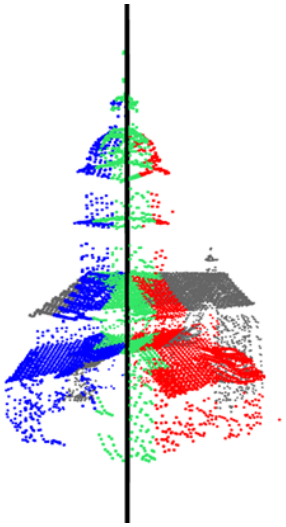


**Figure 24: Local reflectional symmetry detected on a LiDAR point cloud of the Maribor Cathedral. (Source: own)**

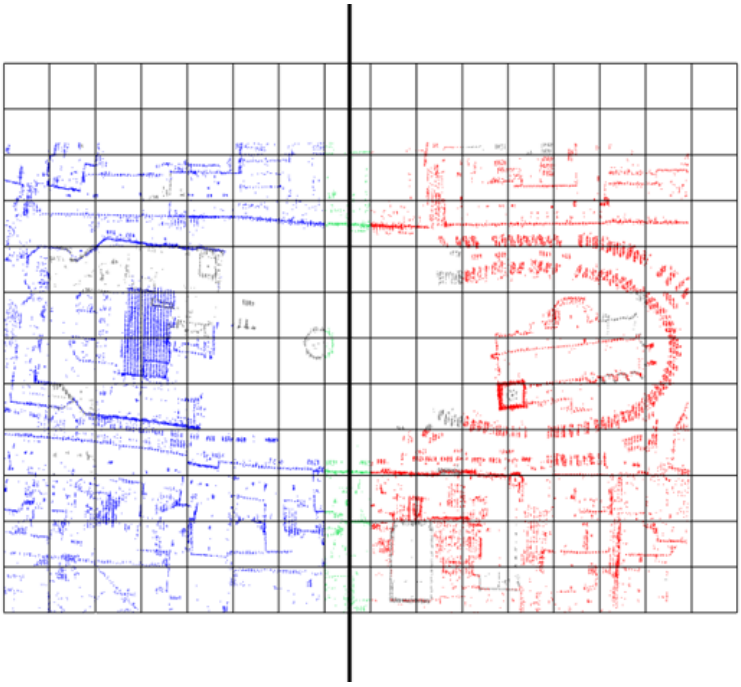


**Figure 25: Local reflectional symmetry detected on a voxelized LiDAR point cloud of Slomšek Square in Maribor. (Source: own)**

# Development and Integration of New Data and Visual Analytics Algorithms into Investigation Platform

Digital forensics is one of the cornerstones of information security today. The daily increase in fraud increases the need for more effective tools and approaches to ensure security. As part of the research and development project, we designed, developed, and integrated new algorithms for data and visual analytics into the existing analytical platform of the client. In doing so, we improved **digital forensic analysis of heterogeneous structured data**, which represents a complex network of different user domains (e.g. financial data flows, social networks, etc.). We also placed special emphasis on algorithms in the field of artificial intelligence to perform improved data analytics, where hidden information and anomalies in complex networks could be found in an automated way. We upgraded visual analytics tool with the introduction of new visualization algorithms for the presentation of multidimensional data and the possibility of including new heterogeneous data flows. Together with the study of appropriate algorithms and their integration, we established cooperation between the security authorities of the Republic of Slovenia and the University of Maribor, Faculty of Electrical Engineering, Computer Science and Informatics (UM FERI) in terms of research challenges in national digital security.


## Financed by

ARRS – Slovenian Research Agency, MNZ RS (contract V4–2117)

## Duration

2021 - 2022

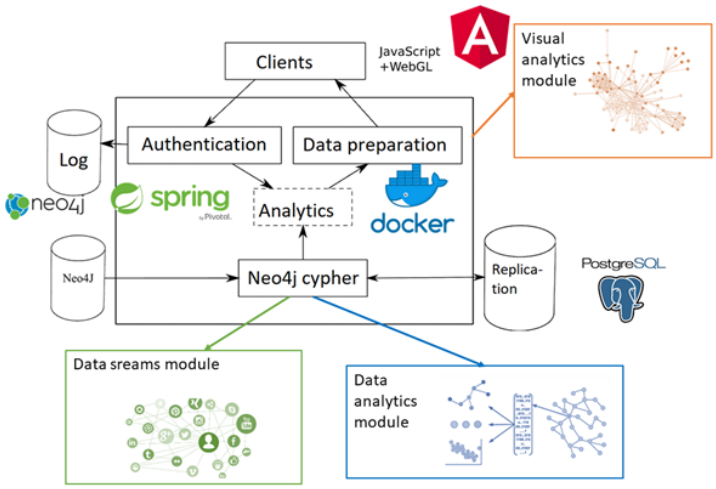




**Figure 26: Components of the advanced investigation platform. (Source: own)**

# Integration and Analysis of Heterogenous Data Streams in Investigation Platform

## Financed by

ARRS – Slovenian Research Agency,
MNZ RS (contract V2–2260)

## Duration

2022 to 2023

Finding useful information in large amounts of heterogeneous data is an increasingly important part of digital forensics, with data in the form of complex networks most often helping to detect new patterns and acquire new knowledge. As part of the research and development project, we are designing **upgrades to the existing analytical platform**, which enables the analysis of data in the form of a complex network. The solutions will enable the integration of **new heterogeneous data streams** (e.g. social network data, telephone conversations, and air passenger data) **into a graph format**. The main innovation will be the possibility of **constructing a new graph over the input data**, in case they are not sufficiently internally connected.

We are additionally defining new data models, examining the suitability of existing algorithms over given data models, and developing new data and visual analytics algorithms to study new input data. As part of the project, we are also introducing the researchers to new advanced techniques. With this project, we are, thus, strengthening cooperation between the security authorities of the Republic of Slovenia and the University of Maribor, Faculty of Electrical Engineering, Computer Science and Informatics (UM FERI).



REPUBLIC OF SLOVENIA
MINISTRY OF THE INTERIOR

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SLOVENIAN RESEARCH AGENCY

# An Integrated Approach for Conservation of Cultural Heritage Wall Paintings

The preservation of cultural heritage (CH) is the only way to effectively transfer it to future generations. Given its importance, the key for a successful preservation of historical materials is a multidisciplinary approach to conservation issues. First step involves fundamental understanding of an individual cultural heritage object and its condition through knowledge-based learning and utilisation of advanced diagnostic and computational techniques. Second step requires appropriate choice and implementation of conservation interventions needed, which can only be achieved through development of methodologies, tools and materials to counteract, stop, and (ideally) revert the degradation process. However, for prolonged preservation of CH, the act of conservation itself is not regarded the final step; in order to ensure the future of CH, validation of the effectiveness of conservation interventions needs to be performed, as well as long-term monitoring of the CH itself.

Wall paintings represent one of the most important types of cultural heritage. As an integral part of architecture, their state of preservation usually reflects the history of architecture itself by displaying degradation, damage, numerous historical treatments and redesigns. Wall paintings, embellishing architectural façades are particularly prone to decay since they suffer direct exposure to environmental conditions.


## Financed by

ARRS – Slovenian Research Agency (contract J2–4424)

## Duration

2022 to 2025

## Partners

UM Faculty of Electrical Engineering and Computer Science, Zavod za gradbeništvo Slovenije, Javni zavod Republike Slovenije za varstvo kulturne dediščine, Igea d.o.o.


Moreover, **digital documentation** can significantly improve the understanding of their present state, as well as **planning of preservation maintenance, presentation and promotion**. Advanced techniques, such as **LiDAR**, can be particularly useful in providing an overall assessment of the entire surface investigated, which can be profitably used to identify those specific areas in which further analytical measurements, sampling, laboratory analysis or conservation-restoration treatments are required. Sometimes sites of interest are difficult to access, or the test fields where conservation and restoration interventions have been carried are no longer available after scaffolding has been removed'. The use of advanced equipment such as **drones** is therefore highly desirable, since they offer faster, more advanced (comparison of 3D models taken before and after the procedure), safer and cheaper analysis (no "roadblocks", scaffolding, permits, or safety requirements e.g. helmets and seat belts) of the object condition. Furthermore, when new materials are developed (such as the new cleaning and consolidation procedures presented in this project), it is very important to monitor the condition of the materials following such interventions, as the long-term effectiveness of such interventions is often still unexplored.

# Patient Individualised Management of Endometrial Cancer

## Financed by

ARRS – Slovenian Research Agency (contract J3–4523)

## Duration

2022 to 2025

## Partners

UM Faculty of Electrical Engineering and Computer Science, University medical center Maribor, UM Faculty of Medicine, UM Faculty of Chemistry and Chemical Engineering, University medical center Ljubljana

Gynaecological cancers represent a unique group of cancers associated with the endocrine physiological regulations in the body. Standard management of these cancers often has a significant impact on the hormonal balance in women and can lead to significant debilitating consequences due to early menopause or loss of reproductive function. Endometrial cancer is the most common gynaecological malignancy in the developed world and in women younger than 40 years represent up to 5% of cases and around 20% of women are diagnosed before menopause.

Although most endometrial cancers are diagnosed early, up to 20% progress to high-stage carcinoma. Current diagnostic approaches fail to identify high-risk disease that is apparently early stage at presentation. This indicates the need for improvement in risk assessment and subsequent management of these women.

Current risk assessment is based on clinical or integrated molecular group classifications endorsed by the ESGO/ESTRO/ESP guidelines. These classify endometrial cancer into 4 distinct groups. These groups are POLEmut (Polymerase Epsilon–Mutated), MMRd (Mismatch Repair Deficiency), p53abn (p53 Abnormal) and NSMP (no specific mutational profile).

The NSMP represents the largest group. Considering the heterogeneity in prognosis, there is a great need for additional specific biomarkers. Improved risk assessment will enable therapy de-escalation and a safer approach to non-standard, fertility sparing therapy (FST). This will ultimately enable individualised counselling and patient focused treatment. Following this path, we should be able to shift the focus from oncological outcomes to improvement of long-term patient reported outcomes (PROs).

In the project, we will address the current unmet needs in women with endometrial cancer by:

- **Identifying new biomarkers** (WP1) to improve risk stratification, de-escalating therapy, identifying candidates for non-standard therapy, such as FST or hormone replacement therapy;
- Developing **conventional and smart risk stratification algorithms** (WP3) to incorporate these biomarkers;
- **Developing minimally invasive methods of diagnostics and screening** (WP2) that would allow accurate risk stratification, early diagnostics and possible screening in high-risk populations.

Finally, following the results of our research, our ultimate goal is to **improve PROs** (WP4). We will first recruit patients at both national tertiary centres to obtain the necessary biological samples and precise tumour imaging data. Through sample analysis, we will determine the established molecular classification and analyse for the presence of new biomarkers.

In addition to evaluating biomarkers in standard therapy, UMC Maribor will lead research of the molecular classification and biomarkers role in FST. This will provide fresh insight on the impact of tumour biology on reproductive and oncological outcomes of FST. Furthermore, we will focus on the possibility of obtaining the diagnosis and the biomarker-based risk assessment non-invasively. The project will focus on **developing liquid biopsy methods and analysis of cell-free DNA and cell-free RNA** in women with endometrial cancer to **enhance individualised management**.

The main purpose of introducing novel biomarkers to clinical practice is to improve patient tailored management and possibly use less aggressive management in low risk patients. Hence, we have designed "in-vitro" studies of standard and unconventional therapeutic approaches to molecularly characterised endometrial cancer. For this purpose, we will for the first time characterise our own and commercially available endometrial cancer cell lines. The findings of these studies will have major implications for the design of subsequent clinical trials. All the knowledge gained through our project will be integrated to design a **better, clinically applicable risk stratification model**. The findings will culminate in better possibilities for tailored management and precision medicine, especially in young, low-risk women with endometrial cancer.

# DIGISAD –Development and introduction of digital tools to support fruit production

## Financed by

ARRS – Slovenian Research Agency, MKGP RS (contract V4–2230)

## Duration

2022 to 2025

## Partners

UM Faculty of Electrical Engineering and Computer Science, UM Faculty of Chemistry and Chemical Engineering, Kmetijski inštitut Slovenije, Kmetijsko gozdarski zavod Maribor, Kmetijsko gozdarski zavod Nova Gorica, UL Faculty of Mechanical Engineering

Fruit production in Slovenia and beyond is becoming an extremely demanding industry due to the need to adapt to climate change, increasing environmental requirements, and specific market requirements, which both traders and consumers form. To help fruit growers adjust to changed conditions more easily, we will develop tools that will help them make decisions regarding the approach to producing the highest quality fruit while constantly searching for "internal reserves" and optimizing production processes to achieve economical production. The developed digital tools will enable easy and timely access data from meteorological stations. Digital tools will thus include a **digital handbook with guidelines for identifying pests and diseases, early crop predictions** based on fruit images, and a **tool for determining critical points and the level of risk** when transitioning to more demanding production systems (e.g. from conventional or IP in EKO). As part of the project, we will also continue developing a **customized sprayer.**



REPUBLIC OF SLOVENIA
MINISTRY OF AGRICULTURE, FORESTRY AND FOOD

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SLOVENIAN RESEARCH AGENCY

# COMPROMISE – Data Compression Paradigm Based on Omitting Self-evident Information

Data compression is one of the traditional disciplines of computer science, but one that has made no significant progress in recent decades. It has also failed to keep up with new scientific trends, where new devices collect ever-increasing amounts of highly heterogeneous data. These data are compressed using either domain-dependent or general-purpose methods. The general-purpose methods are well-known lossless solutions from 30 years ago (e.g. RAR or ZIP). They achieve generality by handling the data stream on the level of bytes, ignoring potential higher-level relations in the data. Domain-dependent methods are lossy, near lossless, or lossless. Lossy methods operate by transforming the data into frequency space, performing the quantization there, and encoding the remaining values in a lossless manner, whereby the lossless part is typically domain-dependent as well. Near lossless and lossless methods are significantly different and typically prediction based. However, the prediction is made from a narrow spatial and/or temporal context, which reduces its efficiency. Most methods are symmetric, which means that decoding is performed by the same pipeline as encoding, only in a reversed order.


## Financed by

ARRS – Slovenian Research Agency (contract J2–4458)

## Duration

2022 to 2025

## Partners

UM Faculty of Electrical Engineering and Computer Science, University of West Bohemia (UWB) in Pilsen, Czech Republic


The disadvantage is that the time complexity of decoding is the same as that of encoding, which requires similar infrastructure for both the encoder and the decoder. Finally, each type of data requires a specific solution that is not transferable to other types of data (e. g. audio compression is completely different from compression of raster images). In the COMPROMISE project, we aim to develop a **new data compression methodology** which will be largely domain-independent and asymmetric. By using a unified pipeline of procedures, the methodology will be suitable for lossy, near lossless, and lossless compression. Domain independence will be achieved by **forming feature repertoires in different domains and linking them to a unified domain-independent taxonomy**. In our case, a feature will be any piece of information with high discriminative or predictive value for human interpretation or machine processing (e.g. computer vision, classification) of a data stream. The obtained repertoire of features will be reduced through a domain-independent iterative optimisation process, as long as the set of remaining features will allow the restoration techniques to perform satisfactory reconstruction of the input data. The compression pipeline will be the same for lossy, lossless, and near lossless compression, except that the output in the latter two cases will include the residuals, obtained as the difference between the original and the restored data. The data decompression will be much simpler and will consist of features and residuals decoding, restoration of data from features, and applying residuals in cases of lossless or near lossless mode. This will set the requirements for the decoder substantially lower than those for the encoder. The concept of domain-independent features also allows the information about higher-level relations in the data to be preserved in the compressed form, which improves the reusability of data on different semantic levels.

In order to demonstrate the universality and domain independence of the methodology we will use raster images, digital audio, biomedical signals, and sparse voxel grids in our study. These domains differ in both the data dimensionality and dynamism, while addressing two human perceptual systems – vision and hearing. The proposed domain independent methodology will be implemented with a **unified platform**, which will be used to **demonstrate the efficiency and universality of the COMPROMISE methodology,** to validate the key performance indicators, and to verify the scientific hypothesis. By using the methodology, we expect to achieve **better lossless and near lossless compression ratios** than existing domain-dependent methods, which will set the foundation for a **new generation of data compression methods**.

# International Projects

# HOLISTIC – Wildfire Monitoring and Management System

## Financed by

European Comission, IPA Adriatic Cross-Border Cooperation Programme

## Duration

2014 to 2016

## Partners

UM Faculty of Electrical Engineering and Computer Science, Municipality of Ajdovščina; DAT-CON d.o.o; Slovenia Forest Service; 20 partners from Croatia, Bosnia and Herzegovina, Montenegro, Serbia, Albania, Greece and Italy

## Additional information

**https://www.adriaholistic.eu/**

HOLISTIC aims at development of comprehensive **wildfire monitoring and management system** at the Adriatic seacoast. GeMMA provided a group of experts for environmental and Earth observation data processing for the Municipality of Ajdovščina, where the system is being evaluated in operational environment. An advanced GIS has been developed that provides **real-time decision support** to fire fighters, civil protection, and other first responders. This GIS allows for integration of real-time video-streams from **thermal cameras** and supporting information acquired by **drones**. Integrated analytics tools include navigation support for rescue teams as well as information support for evaluation of burned areas. In addition, the system integrates tracking of units for their improved coordination, supported by automatic routing and mapping of obstacles.

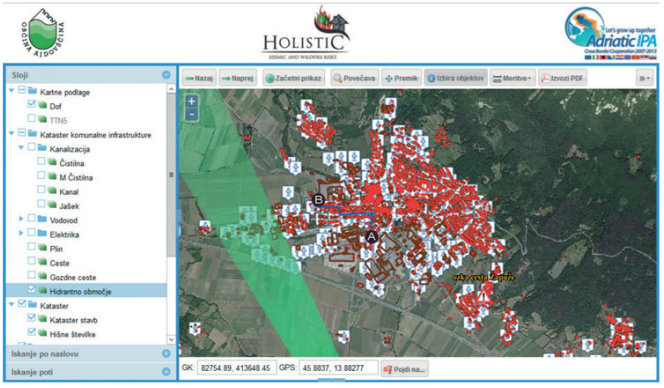



**Figure 27: Current thermal camera view (green), densely populated areas (red), and the route of the fire brigade (blue) from its current position (A) to the fire location (B), together with all the layers of critical infrastructure. (Source: own)**

# MAHEPA – Modular Approach to Hybrid-Electric Propulsion Architecture

MAHEPA is a research project aimed to boost research in the field of **low emission propulsion technology**. Its mission is to open up the potentiality for the series production of **greener airplanes** in order to support European environmental goals in aviation, which require a 70% reduction of greenhouse gases until 2050.

MAHEPA developed new components in a modular way to power two four-passenger hybrid electric airplanes that flew in 2020 and 2021, respectively. The first was equipped with a **hybrid powertrain** utilizing an **internal combustion engine**, and the second was a **fuel cell hybrid-powered** aircraft, showcasing the possibilities for zero-emission long-distance flight as a concrete example of this innovative propulsion technology.

The main results of MAHEPA project were thus novel, modular, and scalable hybrid-electric powertrains capable of running on **alternative fuels or hydrogen with zero emissions**. However, not only new technologies has been developed, but also extended studies have been made on regulatory implications, airport infrastructure requirements, airspace procedural practices, operational safety, operating costs and emission models resulting in a unique outlook for regulators, aviation industry, operators and potential investors.

The role of **GeMMA** was to provide an attractive digital presentation of the designed airplanes with an emphasis on their propulsion systems. We were thus developing:
1) An **augmented reality presentation** of the airplanes' exterior parts and propulsion systems by utilizing the **HoloLens AR technology**;
2) A realistic **3D presentation** of the aircraft cockpit and cabin by utilizing **HTC Vive virtual reality headset**;
3) Multimedia presentation of the airplanes' technical data and generally about the MAHEPA project, displayed on a smartphone and interactively controlled through quick response (QR) codes on a physical model of one of the two developed aircrafts.

## Financed by

EU (H2020 Programme)

## Duration

2017 to 2021

## Partners

UM Faculty of Electrical Engineering and Computer Science, Pipistrel Vertical Solutions d.o.o., Compact Dynamics GmbH, DLR, University of Ulm, H2FLY GmbH, Delft University of Technology, Politecnico di Milano, UM Faculty of Civil Engineering, Transportation Engineering and Architecture

## Additional information

**https://mahepa.eu/**


**Figure 28: Physical model of the MAHEPA aircraft and demonstration of the MS HoloLens AR technology utilization (Foto: D. Podgorelec).**

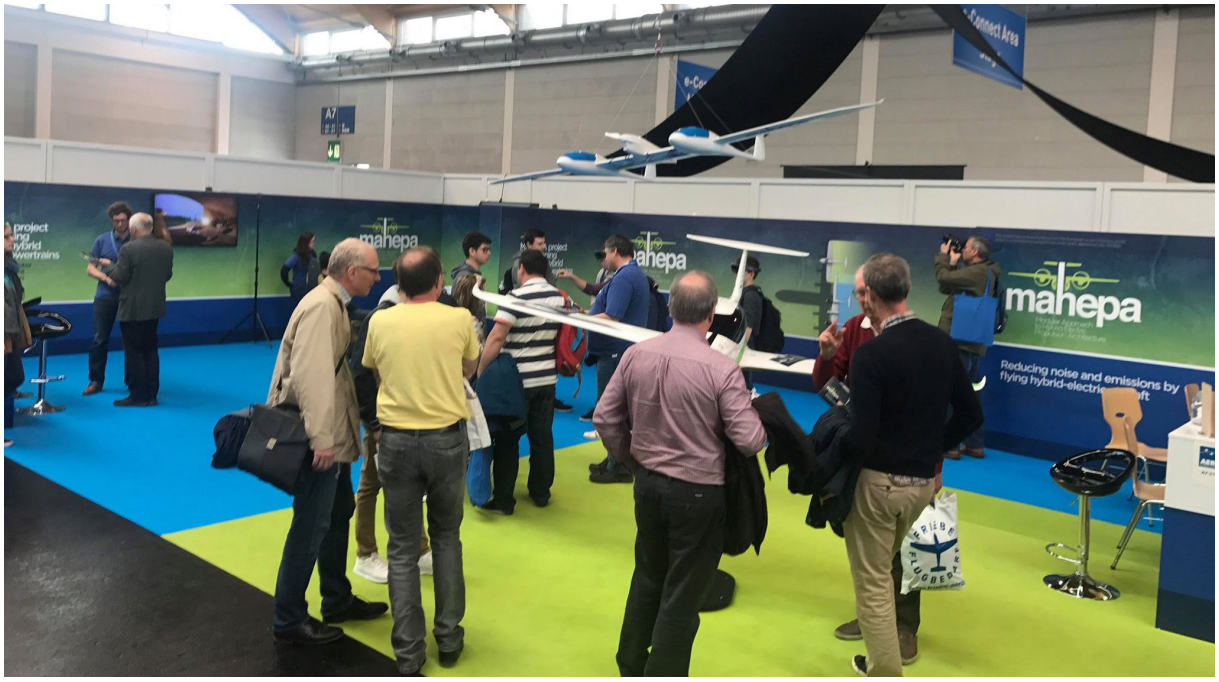



**Figure 29: MAHEPA showroom on AERO 2019 general aviation fair in Friedrichshafen, Germany, powered by GeMMA by digital exhibition tools developed by GeMMA (Foto M. Marksel).**



Co-funded by the Horizon 2020 programme of the European Union

# SmartVillages – Smart Digital Transformation of Villages in the Alpine Space

Alpine Space rural communities are deprived of highly needed jobs, good provision of services as well as a favorable climate for enterprenuership and social innovation, which result in a brain drain. Digitalization is a promising approach to counter the situation. A Smart Village approach for mountain areas could unlock the potential of local actors to make their region a more attractive place to live and work. In cooperation with thirteen partners Smart Villages aims to brings together policymakers, business, academia, and civil society in a quadruple helix approach to improve the framework for innovation through new forms of stakeholder involvement facilitated by Information and Communication Technologies. The Project is a strategic initiative of **EUSALP Action Group 5** and follows an integrative, participatory approach implying a city - village dialogue.

The project contributes to better framework conditions for innovation on two aspects: the organisational and societal part - working with regional support groups involving policy level, academia, business, and civil society - and the technical part - DEP (Digital Exchange Platform) and Toolbox with new digital products - and combining the strengths of both sides. Finally, the transfer of the results to the policy level contributes to improve the political framework conditions for digital innovation.

The DEP enables the transnational knowledge sharing of the overall project findings and European Smart Villages best practices between project partners and the wider public. Toolbox is a combination of tools, methods and techniques that provide the main ingredients of a smart village. It supports and guides project partners, but also other regions within Alpine Space through the participatory establishment of a smart village environments in their regions. Final version of the DEP is available at https://smart-villages.eu/language/en/home/.

Our role was to provide services for smartness assessment, integration of the partners, services for matchmaking and toolbox methods based on survey input, survey management and good practices with automated language translation via Google Translation APIs: Services are consumed by the DEP itself and provide public endpoints for data export to other project partners for further data analytics following the OpenAPI specifications.

## Financed by

Interreg Alpine Space

## Duration

2018 to 2021

## Partners

UM Faculty of Electrical Engineering and Computer Science, Swiss Centre for mountain regions Schweizerische Arbeitsgemeinschaft für die Berggebiete, University of Ljubljana, SmartiS City d.o.o., Poliedra – Politecnico di Milano, Agenzia di Sviluppo Gal Genovese, Energie und Umweltagentur Betriebs-GmbH Niederösterreich, Association pour le Développement en REseau des Territoires et des Services, Regionalverband Südlicher Oberrhein, Bodensee Standort Marketing GmbH, Tiroler Zukunftsstiftung, Software Competence Center Hagenberg, Region Luzern West

## Additional information

**https://www.alpine-space.org/projects/smartvillages/en/home**

# SMART2 – Advanced Integrated Obstacle and Track Intrusion Detection System for Smart Automation of Rail Transport

## Financed by

EU (H2020 cascade funding Shift2Rail)

## Duration

2019 - 2022

## Partners

UM Faculty of Electrical Engineering and Computer Science; Universität Bremen, Germany; OHB Digital Services GmbH, Germany; Univezitet u Nišu, Serbia; HARDER Digital SOVA d.o.o. Niš, Serbia; Universitatea Tehnica Cluj-Napoca, Romania; Newcastle University, The United Kingdom; FOKUS TECH napredne tehnologije d.o.o., Slovenia

## Additional information

**https://smart2rail-project.net**

SMART2 project was aimed to build a holistic **trackside obstacle detection** (OD) and **track intrusion detection** (TID) systems with corresponding interfaces to a **central decision support system** (DSS). Different remote sensing technologies, including video imaging cameras, thermal imaging cameras, 3D time of flight cameras, radar, and LiDAR, were thus incorporated by individual partners of the strong internation consortium. FOKUS TECH d.o.o. and GEMMA as their subcontractor were responsible for 3D LiDAR sensors for monitoring dangerous areas at level crossings of railway and roads. FOKUS TECH has developed its own 3D LiDAR, which is mounted on a pole near a level crossing, while GeMMA has developed **software for detecting obstacles** on the crossing near and within the dangerous area. The former are indicated with green bounding boxes and the latter with the red ones in the service application, while the dangerous area is bounded with blue polygon edges. The sensor covers a spatial angle of 60° x 30° and has a range of 40 m. This is sufficient for most level crossings on double-track lines. However, two systems could be used for larger crossings and more complex situations.


**Figure 30: LiDAR sensor (in a yellow circle) installed on a pole at the level crossing (Foto: archive of FOKUS TECH d.o.o.).**

**Figure 31: Test scenario and acquired point cloud with obstacles (Foto: archive of FOKUS TECH d.o.o.).**

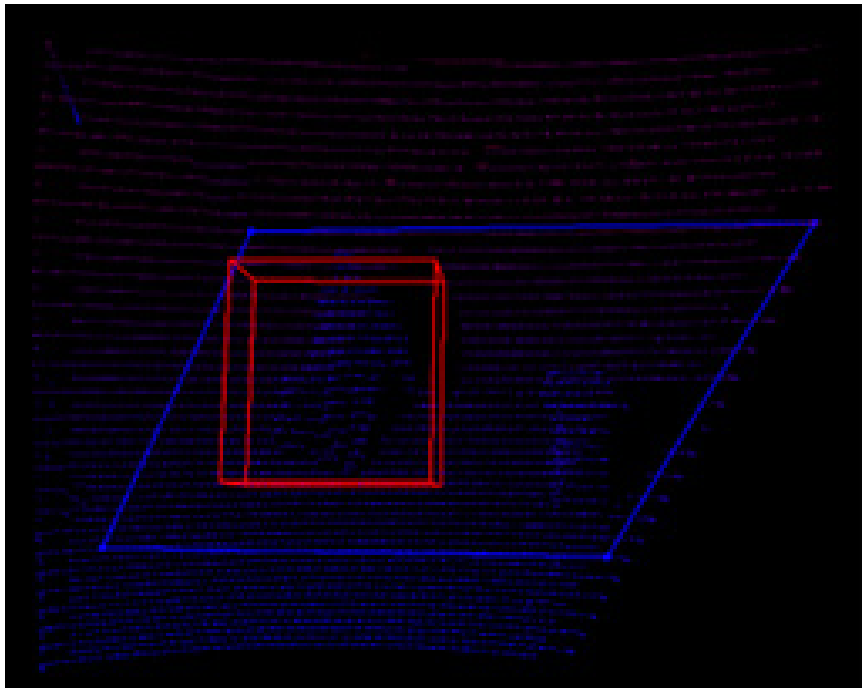


**Figure 32: Detected human (red bounding box) in the dangerous area (blue polygon). (Source: own)**

# STAMINA – Demonstration of Intelligent Decision Support for Pandemic Crisis Prediction and Management Within and Across European Borders

## Financed by

EU (H2020 Programme)

## Duration

2020 to 2022

## Partners

UM Faculty of Electrical Engineering and Computer Science, EXUS, ICCS, AIT GmbH, Crisisplan B.V., Intrasoft S.A, Squaredev, Satways, Trilateral Research LTD, EE Viopliroforikis Kai Ypologistikon Epistimon, Eigen vermogen van het Instituut voor Landbouw- en visserijonderzoek, MCS Datalabs, Innosystems, Brunel University London, Istituto per L'interscambio Scientifico, Verisk Analytics GmbH, Westfaelische Wilhelms-universitaet Muenster, BYS group, Technologicka Platforma Energetickabezpecnost CR ZS, Institut Pasteur de Tunis, Beia Consult International SRL, Erasmus Universitair Medisch Centrum Rotterdam,

STAMINA develops an **intelligent decision support toolset for pandemic prediction and management** and demonstrates its use by practitioners at national and regional levels within and across EU borders. The STAMINA toolset enables national planners and first responders to anticipate and respond to the the "known-unknowns" in their daily effort to enhance health security. Main functionality of the toolset includes:

- Real-time web and social media analytics aiming at public trust monitoring and flagging possible disease outbreaks;
- POCT (point of care testing) and smart wearable diagnostic devices for first line screening;
- Predictive modeling of pandemic outbreak and its impact, along with decision-making support in implementing mitigation strategies;
- Early Warning System;
- Crisis management tool defining the roles and actions of key actors during crisis management;
- Scenario Generation tool for creation of training scenarios;
- Common Operational Picture as the main interface of the solution enabling timely and coordinated response.

The toolset is accompanied by a set of Guidelines on effective implementation of risk communication principles and best practices in cross-organisational preparedness and response plans. The use of the STAMINA toolset will be demonstrated through 12 national and regional small-scale demonstrators and one large-scale cross-border simulation exercise involving all consortium partners.

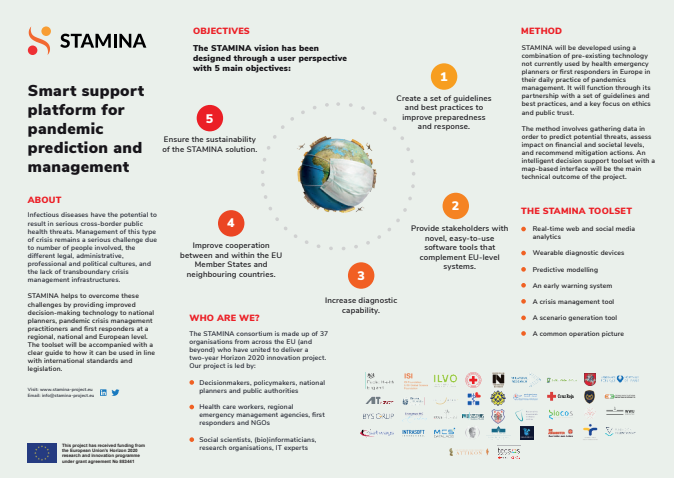



**Figure 33: Project abstract.**
**(Source: https://stamina-project.eu/flyer-and-brochure/)**

There are three laboratories involved on behalf of UM FERI in this project:

- Laboratory for Geospatial Modelling, Multimedia and Artificial Intelligence (GeMMA);
- Laboratory for System Design;
- System Software Laboratory

GeMMA coordinated the developments in support of technology integration and implementation of real-world use-cases, carried out at Zdravstveni dom dr. Adolfa Drolca Maribor.

## Partners

Assistance Publique - Hopitaux de Paris, Zdravstveni dom dr. Adolfa Drolca Maribor, Johanniter Osterreich ausbildung und forschung gemeinnutzige GmbH, Cruz Roja Espanola, Red Cross district 5 Bucharest, Ethniko kai kapodistriako panepistimio athinon, Fundacion de la comunidad Valenciana para la investigacion, promocion y estudios comerciales de Valenciaport, Ayuntamiento de Valencia, ethnikos organismos dhmosias ygeias, Nacionalinis visuomenes sveikatos centras prie sveikatos apsaugos ministerijos, Ministry of health, Turkiye Cumhuriyeti Saglik Bakanligi, Observatoire National des Maladies Nouvelles et Emergentes, Department of health, ministry of the interior of the Czech Republic, Institutul de Virusologie Stefan S. Nicolau.

## Additional information

https://stamina-project.eu/

# CobotSense – Intelligent 3D Safety Sensor for Cobot Applications

## Financed by

COVR award (H2020 cascade funding)

## Duration

2020 to 2021

## Partners

UM Faculty of Electrical Engineering and Computer Science, FOKUS TECH d.o.o., FANUC ADRIA d.o.o.

## Additional information

**https://www.safearoundrobots.com/home**

COVR (Being safe around collaborative and versatile robotos in shared spaces) is an EU-funded H2020 project aimed to determine protocols how to test and validate **safety for collaborative robot (cobot) applications or components**. The protocols are being developed by third parties in series of smaller projects – COVR awards, CobotSense being one of them.

In the Factories of the Future, humans and cobots will share common workspace to enable more flexible and cost-effective production. In this new paradigm, small cobots are already a reality, but this is not the case for big robots and heavy-duty applications. New 3D safety sensors and intelligent control systems (ICS) are needed for these new cobot applications, but they are unfortunately not available on the market yet. To fill this gap, the CobotSense partners have developed such **a novel laser-based 3D safety sensor with an associated ICS**.

The goals of CobotSense, all successfully achieved, were:

- Advances on development of the prototype 3D LiDAR sensor for cobot applications. The key performance indicator (KPI) here is reaching the scanning speed of up to 5 frames per second;
- ICS development. The KPI here is the validated protective separation distance (PSD) calculation for speed and separation monitoring (SSM) cobot applications. This was achieved by developing and integrating the software modules for: registration of the scanned point cloud and the robot's geometric data; determination of the robot's pose by the developed forward kinematics model; the scene segmentation into the robot, static obstacles, and operator; motion prediction for both, robot and operator; the PSD calculation; and real-time adjustment of the robot's speed in order to realize the SSM principle;
- Specification of use cases for testing the integration of a robot, operator, sensor and ICS in laboratory and industrial environments. A COVR case story was described (https://youtu.be/cEMr60nl1hE), and the COVR protocol for testing SSM cobot applications monitored with 3D sensors was developed and specified (https://covrfilestorage.blob.core.windows.net/documents/protocols/ROB-MSD-3-Test_3D_Safety_Sensors_in_Speed_and_Separation_Monitoring_Cobot_Applications.pdf).

Two UM FERI labs (Laboratory for Geospatial Modelling, Multimedia and Artificial Intelligence, and Laboratory for Cognitive Systems in Mechatronics) participated mainly in the ICS development and COVR protocol preparation.

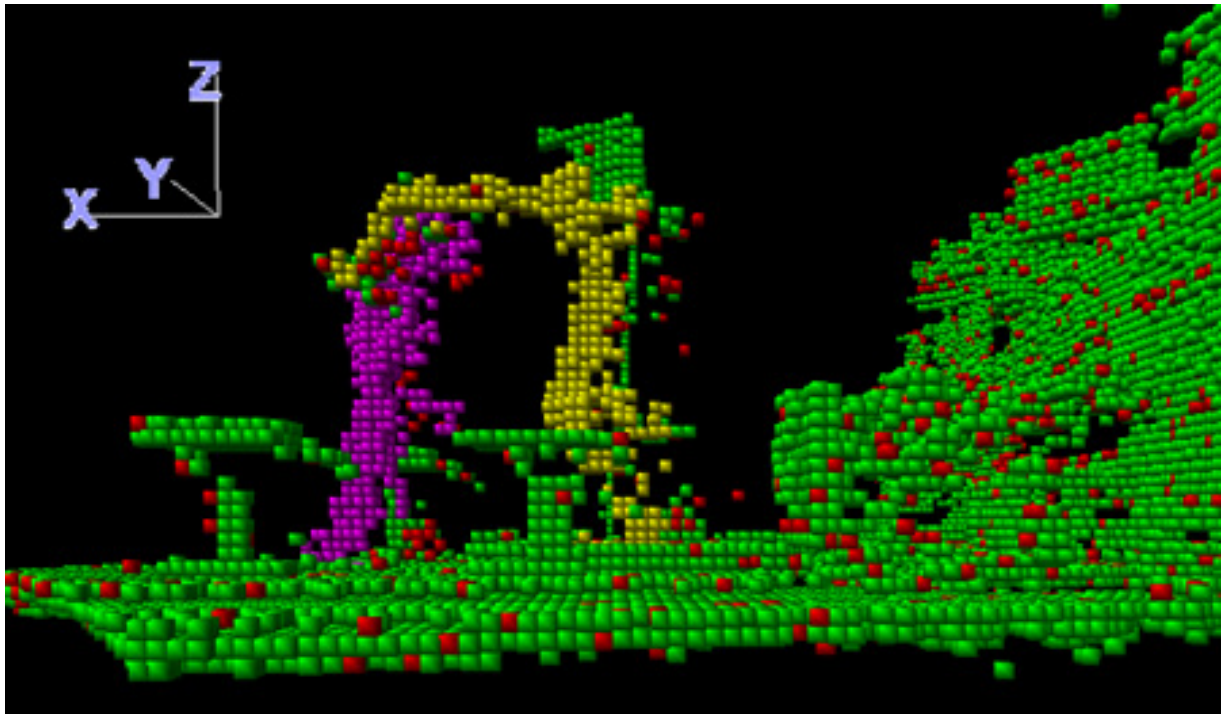



**Figure 34: Cobot (yellow), operator (magenta), static obstacles (green), and noise (red) in the voxelized scene. (Source: own)**

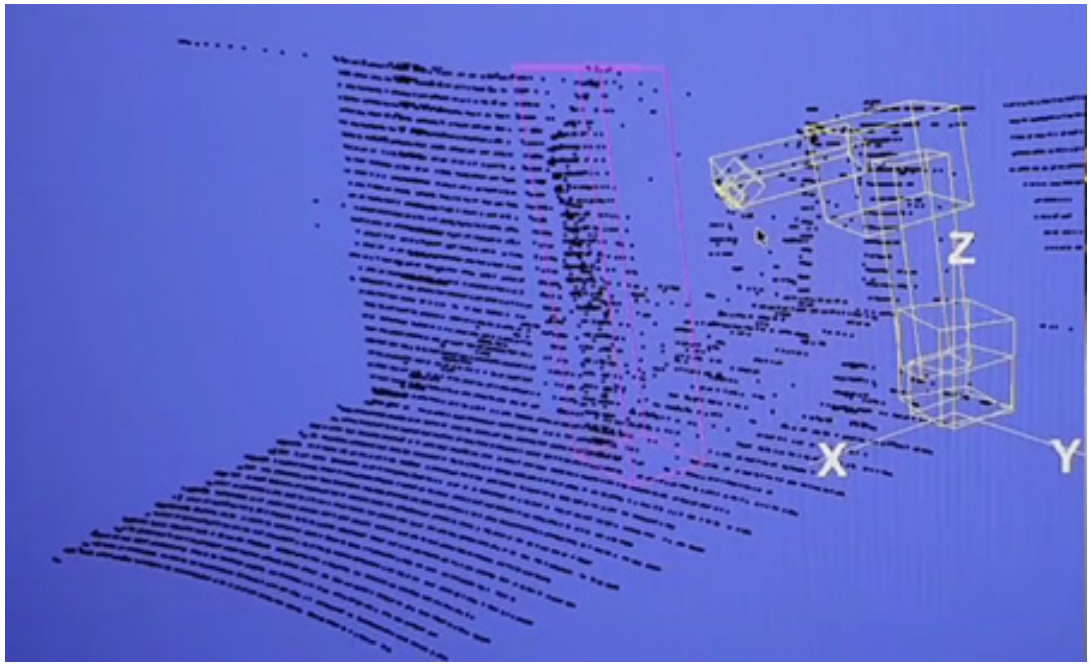



**Figure 35: Bounding boxes of the robot links and the operator. (Source: own)**

# InspectRAIL – Autonomous Mobile Robots for Inspection of Railway Lines

## Financed by

EU (H2020 funded RIMA Network)

## Duration

2022

## Partners

UM Faculty of Electrical Engineering and Computer Science, FOKUS TECH d.o.o., ALTPRO d.o.o., Croatia

## Additional information

**https://rimanetwork.eu/**

Railway safety is threatened by landslides, falling rocks and trees, floods, collapses of rail lines and load-bearing structures, torrents, and other hazards. Unlike the SMART2 project, where statically installed LiDAR sensors were used to monitor dangerous areas at level crossings of railway and roads, much wider open sections of railways require a new concept for inspection. InspectRAIL thus introduced inspection by **autonomous mobile robots**, which move through dangerous places along the railway lines on steel cables stretched between the catenary masts and operate in all weather conditions. The robots are equipped with LiDAR sensors and video cameras which inspect the railway tracks. The acquired data is automatically processed and sent to the **Intelligent Control System** (ICS), signaling system, traffic control, and maintenance centre for further actions. As movement requires higher frame rates than statically mounted sensors, a contemporary Ouster OS1 LiDAR sensor was chosen.

GeMMA participated as a subcontractor of the project partner FOKUS TECH d.o.o. and was responsible for developing the ICS, where several challenges had to be addressed. Detection of rails was initially designed on the reflectivity measurements performed by the utilized sensor, but this solution was not stable enough in varying weather conditions, so we had to rely entirely on geometric data only.

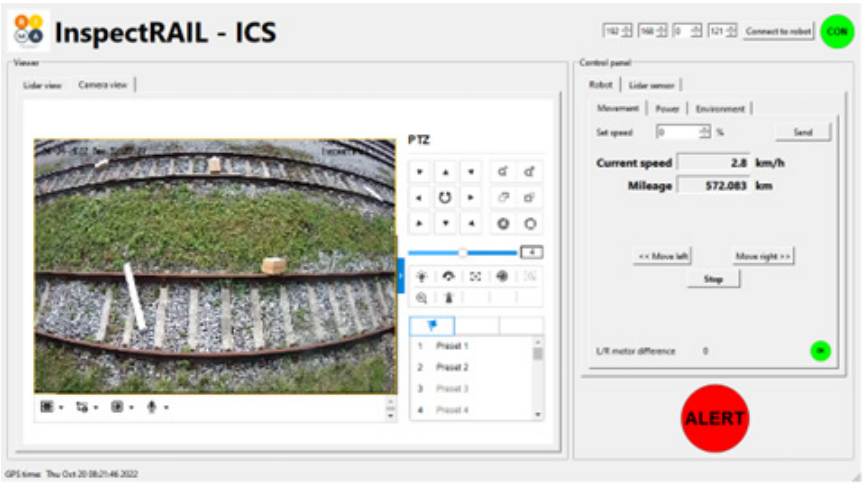



**Figure 36: The Camera view of the ICS with alert indicator due to detected obstacles. (Source: own)**

In normal conditions, the rails are about 15 cm above their surroundings, but we had first to align the point cloud due to sagging of the wires and the robot tilt due to wind. An external inertial measuring unit (IMU) was used for this task, which requires synchronization with LiDAR among all. The obstacle detection is then performed in a simple manner. LiDAR points detected below the top of the sleeper (TOS) plane in the section of the railway track correspond to lack of the ballast and must be reported as a potential danger. The second dangerous section is above the top of rail (TOR), where no obstacle should be detected. Besides detecting the obstacles and sending alerts, ICS must also display the mileage which represents the position of the robot relative to the reference rail system. The mileage is calculated from the data of the encoders of the drive motors and the radio frequency identification (RFID) tags on the poles of the overhead contact line.

**Figure 37: Besides the obstacles above the rails, the system must also detect holes in the track ballast (Foto: archive of FOKUS TECH d.o.o.).**

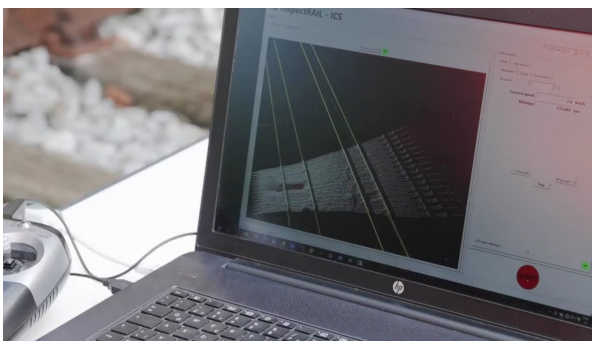


**Figure 38: The LiDAR view of the ICS with detected rails (yellow) and obstacles (red) in the point cloud (Foto: archive of FOKUS TECH d.o.o.).**

**Figure 39: The robot (in the yellow circle) with LiDAR and camera during the detection of obstacles in the test area (Foto: archive of FOKUS TECH d.o.o.).**

# PLOTO – Deployment and Assessment of Predictive Modelling, Environmentally Sustainable and Emerging Digital Technologies and Tools for Improving the Resilience of IWW Against Climate Change and Other Extremes

## Financed by

EU (Horizon Europe Programme)

## Duration

2022 to 2026

## Partners

UM Faculty of Electrical Engineering and Computer Science, Intrasoft International SA, Exus, Budapesti Muszaki es Gazdasagtudomanyi Egyetem, Diadikasia Business Consulting Symvouloi Orgszagos Egyesulet, Universite de Liege, Asministrativa Fluviala a Dunarii de Jos R.A. Galati, Universitatea Danubis din Galati, Romanian River Transport Cluster, MAV Magyar Allamvasutak Zartkoruen Mukodo Reszveny Tarsasag, National Technical University of Athens,

PLOTO aims at increasing the resilience of the Inland WaterWays (IWW) infrastructures and the connected land- infrastructures, thus, ensuring reliable network availability under unfavourable conditions, such as extreme weather, accidents and other kind of hazards.

Our main target is to combine downscaled climate change scenarios (applied to IWW infrastructures) with simulation tools and actual data, so as to provide the relevant authorities and their operators with an integrated tool able to support more effective management of their infrastructures at strategic and operational levels.

Towards this direction, PLOTO aims to:

- Use **high resolution modelling data for the determination and the assessment of the climatic risk** of the selected transport infrastructures and associated expected damages;
- Use existing data from various sources with new types of sensor-generated data (computer vision) to feed the used simulator;
- Utilize tailored weather forecasts (combining seamlessly all available data sources) for specific hot-spots, **providing early warnings with corresponding impact assessment in real time**;
- **Develop improved multi-temporal, multi-sensor UAV- and satellite-based observations** with robust spectral analysis, computer vision and machine learning-based assessment for diverse transport infrastructures;

- Design and implement an integrated **Resilience Assessment Platform environment** as an innovative planning tool that will permit a quantitative resilience assessment through an end-to-end simulation environment, running "what-if" impact/risk/resilience assessment scenarios. The effects of adaptation measures can be investigated by changing the hazard, exposure and vulnerability input parameters;
- Design and implement a **Common Operational Picture**, including an enhanced visualisation interface and an **Incident Management System**.

The PLOTO integrated platform and its tools will be validated in three case studies in Belgium, Romania and Hungary.

## Partners

RISA Sicherheitsanalysen GmbH, Ilmatieteen Laitos, Budapesti Szabadkikoto Logistzikai Zrt., Societal and Resilience Climate Change Centre of Excellence, Service Public de Wallonie, Aristotelio Panepistimio Thessalonikis, European road transport Telematics implementation coordination organisation - Intelligent transport systems & services Europe, Satways

# PrAEctiCe – Potentials of Agroecological Practices in East Africa with a Focus on Circular Water-energy-nutrient Systems

## Financed by

EU (Horizon Europe Programme)

## Duration

2022 to 2026

## Partners

UM Faculty of Electrical Engineering and Computer Science, Hochschule Karlsruhe, Steinbeis 2I GmbH, Aquabiotech Limited, Prototipi Limited, Goeteborgs Universitet, Makerere University, Uganda Martyrs University, Ministry of Agriculture Livestock and Fisheries Kenia, Regional Universities Forum for Capacity Building in Agriculture, National Agricultural Research Organisation, Maseno University, Sustainable Agriculture Tanzania, Aquagri, Alliance for Food Sovereignty in Africa, Africa Agribusiness Academy

PrAEctiCe will provide a novel agro-ecology indicator set for East Africa, aimed at **helping smallholder farmers in their agro-ecological transition**.

The project goes beyond the existing indicator frameworks by putting the "concept into action" with a decision support tool for agro-ecology advisors supporting the selection of the best suited combination of agro-ecological practices in a local context. In addition, it puts a focus on circular water-energy-nutrient systems of integrated aqua-agriculture, and practice with high potential for efficient farming with minimal climate impacts, which has not been sufficiently explored in previous indicator work. Through a multi-stakeholder approach, new insight on agro-ecological practices in East Africa will be gathered to inform on existing successful practices as well as the barriers and drivers of East African smallholder farmers. This insight will help develop an indicator framework for agro-ecology, which, while building on existing frameworks, is adapted to the East African context and captures integrated aquaagriculture practices in detail.

The PrAEctiCe decision support tool will then, at the farm level, help assess environmental and socioeconomic impacts, with a particular focus on impacts on climate change mitigation and adaptation as well as financial viability. The tool will be validated in three living labs, situated in Kenya, Uganda and Tanzania, covering different integrated aqua-agriculture farming set-ups. Knowledge sharing activities through trainings, student exchanges and events, ensure the dissemination of results across East Africa and between African Union and EU. To reach practitioners at every level, a cascade training mechanism with a train-the-trainer course will help agro-ecology advisors train farming representatives at the local level who then will help the farmers in their agroecological transition. Policy recommendations for African Union and EU policies will round off the project.



Horizon Europe

Funded by the European Union

# Green.DAT.AI – Energy-efficient AI-Ready Data Spaces

GREEN.DAT.AI aims to channel the potential of AI towards the goals of the European Green Deal, by developing novel **Energy-Efficient Large-Scale Data Analytics Services**, ready-to-use in industrial AI-based systems, while reducing the environmental impact of data management processes.

GREEN.DAT.AI will demonstrate the efficiencies of the new analytics services in four industries (Smart Energy, Smart Agriculture/Agrifood, Smart Mobility, Smart Banking) and six different application scenarios, leveraging the use of European Data Spaces.

The ambition is to exploit mature (TRL5 or higher) solutions already developed in recent H2020 projects and deliver an efficient, massively distributed, open-source, green, AI/FL - ready platform, and a validated go-to-market TRL7/8 Toolbox for AI-ready Data Spaces. The services will cover AI-enabled data enrichment, Incentive mechanisms for Data Sharing, Synthetic Data Generation, Large-scale learning at the Edge/Fog, Federated & Auto ML at the edge/fog, Explainable AI/Feature Learning with Privacy Preservation, Federated & Automatic Transfer Learning, Adaptive FL for Digital Twin Applications, Automated IoT event-based change detection/forecasting.

The GREEN.DAT.AI Consortium consists of a multidisciplinary group of 17 partners from 10 different countries (and one associated party), well balanced in terms of expertise. The vast majority of partners already have key roles in a number of projects funded under the Big Data PPP (ICT-16-2017) topic, namely BigDataStack, CLASS, Track & Know, and I-BiDaaS and are serving as active members of the BDVA/DAIRO Association, FIWARE, AIOTI, and ETSI. In addition, partners come from a variety of sectors, such as banking, mobility, energy, and agriculture, constituting a representative workforce of their respective domains, which will contribute to industry adoption and stimulate uptake in other sectors as well.

## Financed by

EU (Horizon Europe Programme)

## Duration

2022 to 2025

## Partners

UM Faculty of Electrical Engineering and Computer Science, Inlecom Innovation Astiki Mi Kerdoskopiki Etaireia, University of Piraeus Research Centre, Consiglio Nazionale Delle Richerche, Konnecta Systems Limited, Atos IT Solutions and Services Iberia s.l., Erevnitiko Panepistimiako Institouto Tilepikononiakon Systimaton, ITC - Inovacijsko tehnološki grozd Murska Sobota, Caixabank SA, Ferrovial Servicios SA, Aegis IT Research GmbH, Red Hat Israel Ltd., Inesc tec - Instituto de Engenhariade Sistemas e Computadores, Tecnologia e Ciencia, Waboost razvoj tehnologij d.o.o., CNET Centre for New Energy Technologies SA, Intasoft International SA, SUNESIS, inovativne tehnologije in storitve,d.o.o., Sphynx Technology Solutions AG

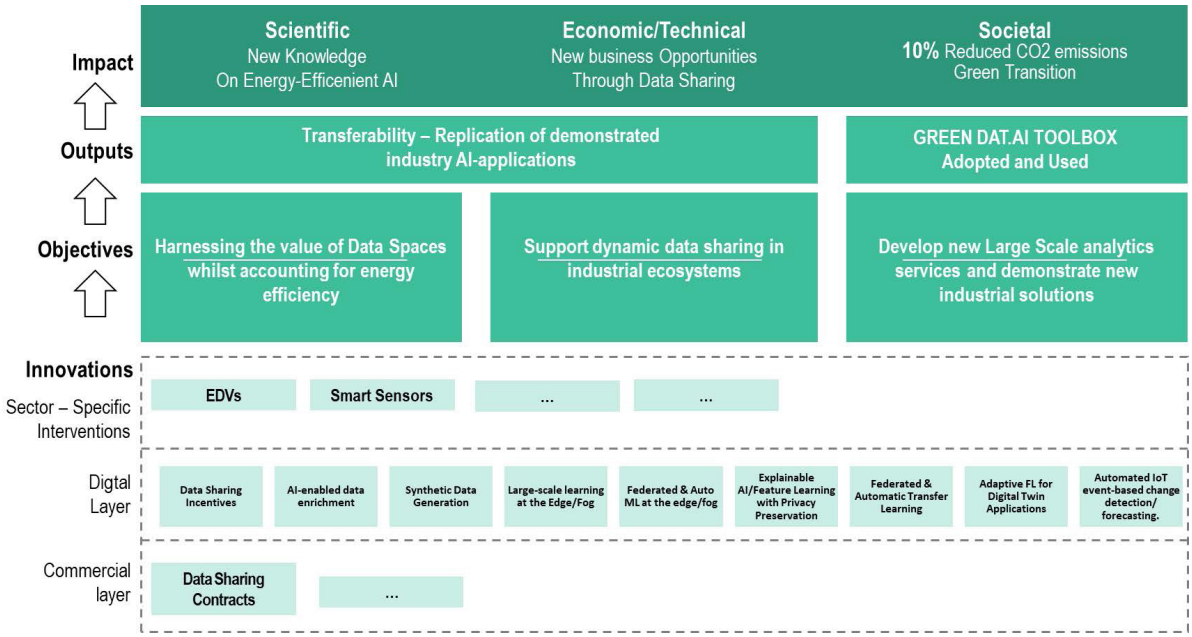



**Figure 40: GREEN.DAT.AI vision & pathways towards impact at a glance.(Source: own)**



Horizon Europe
Funded by the European Union

# INDY – Energy Independent and Efficient Deployable Military Camps

This is a European Defence Fund project lead by **Laboratory for power engineering** at UM FERI, where GEMMA lab. is a collaborating partner. Both at national and international levels, the energy transition is high on the priority list. In line with the "Green Deal", the greening of military forces is necessary to reach the ambition defined by Member States. At the moment, deployable military camps are almost 100% dependent on fossil fuel. This not only means that the environmental footprint is high but it also represents a weak point and vulnerability for the armed forces in terms of logistics and dependence on fossil fuels. This is becoming even more challenging given the growing need of energy for the military equipment.
INDY proposes a **roadmap toward energy independent and efficient systems for military camps**.

The necessary energy transition for deployable military camps will require a change of paradigm for energy production, conversion, storage, transport, distribution and usage, with the final goal of a total independency of fossil fuels. The ambition of INDY is to define a new approach to energy as a whole from energy production to its final usage.

INDY's expected outcome is a strategic roadmap, based on technological and methodological studies, for the development and implementation of disruptive and new energy sources, the management of resources and optimization of needs of military deployable camps. It will be a first step to a better security of supply of energy and the transition to renewable energy sources for future military camps.

## Financed by

EU (European Defence Fund)

## Duration

2023 to 2025

## Partners

UM Faculty of Electrical Engineering and Computer Science, TECES, Tehnološki center za električne stroje, AVL List GmbH, CAFA TECH OU, CNV CONSULTING, Commissariat à l'Energie Atomique et aux Energies Alternatives, Equipos Móviles de Campaña ARPA, SAU, Fraunhofer Gesellschaft, INDRA SISTEMAS, SOCIEDAD ANÓNIMA, INEO DEFENSE, INSTITUTO NACIONAL DE TECNICA AEROESPACIAL ESTEBAN TERRADAS, Institutt for energiteknologi, INTRACOM DEFENCE SINGLE MEMBER S.A., JOHN COCKERILL SA, KOLEKTOR sETup , storitve energetskega upravljanja , d.o.o, Leonardo Società per azioni

# International bilateral projects

# Research on Abnormal Behaviour Detection and Warning in Real-time Video Surveillance Based on Multimedia Algorithms

With increasing importance of social public security and rapid development of video surveillance, social public security depends more and more on video image surveillance systems. Video image surveillance system has become important indispensable infrastructure for public security. Traditional video surveillance systems only display and record video information. Methods of data processing are usually done by real-time manual monitoring or manual postprocessing. Real-time analysis cannot be done, especially during the unexpected or abnormal events. Moreover, data amount accumulates to terabytes of recorded videos. Because of large amounts of video cameras, it is difficult to find abnormal events or accidents in a reasonable time, whilst querying useful information from the video database.

In order to eliminate any potential accident danger and handle the events without any delay, we have collaborated on solving this issues through the bilateral project. We extracted key data from video surveillance system and analysed important information. We have put emphasis on state-of-the-art technology and algorithms for real-time video surveillance that take the advantages of image processing and machine learning.


## Financed by

ARRS – Slovenian Research Agency (contract BI–CN/14–15–007)

## Duration

2015 to 2016

## Partners

UM Faculty of Electrical Engineering and Computer Science, Dalian Minzu University, China


Our goal was to automatically analyse real-time video information input, extract the foreground images and update background images, detect and track moving targets, analyse the tracking targets, and perform an early warning in case of abnormal behaviour. This is the initiative and intelligence of video surveillance system. These algorithms provide **24 hours real-time monitoring and intelligent analysis of the captured information**. In case of abnormal cases, the system provides an alarm in time to avoid possible accidents. Hence, such system shall save material and financial resources required of employing monitor workers.

# Pruning by Numbers: Integrating Tree Physiology with Growth Simulation and 3D Reconstruction to Optimize Apple Tree Pruning


## Financed by

ARRS – Slovenian Research Agency (contract BI–US/17–18–012)

## Duration

2017 to 2018

## Partners

UM Faculty of Electrical Engineering and Computer Science, Purdue University , USA


Tree pruning is one of the most important measures to ensure high yield performance by maintaining a balance between vegetative and reproductive growth. This task is at each year before the growing season carried out manually by tree growers and requires a deep understanding of tree physiology to predict a tree response to the pruning and years of practice. To increase the understanding of tree reactions to pruning, the appropriate computer models were developed very early. The first such model can be found in 1996 when the virtual reality application for apple tree growth after the pruning was presented.

Since then, a lot of simulators have been developed for various types of fruit trees (e.g. peach, cherry, and walnut), but apple trees have by far retained the most attention of researchers. Recent software simulators took full advantage of graphical processing units, which enables realistic real-time tree visualization. A good example of new generation simulators is IMapple, which incorporates a precise functional-structural tree growth model for Golden Delicious apple trees, based on long-time measurements with a photorealistic tree visualization employing 3D manifold watertight meshes for representing the tree geometry, together enabling interactive tree growth simulation including flowering and fruiting. Interactive simulation and faithful 3D geometric models is also offered by EduAPPLE, an interactive teaching tool for apple tree crown formation, where user trains a one-year-old apple tree in the form of an unbranched whip towards the desired tree form using different tree training techniques. The growth model in EduAPPLE incorporates only the most basic tree growing rules, common to all cultivars while growing conditions are modeled with random variables to maximize tool generality. However, in order to improve users' pruning skills, this is not enough. To do that, the teaching tool has to take a more active role and start to suggest to the user which branches have to be removed in order to achieve the best results. The first step in that direction represents the work, where the pruning is presented as a combinatorial optimization problem of performing the cuts on a virtual tree model in order to achieve the best light distribution inside the tree crown, which is a good start, but not sufficient to actually be used as a recommendation system. Recent advances in 3D geometric modeling have shown an unprecedented precision in detailed reconstruction, inverse modeling, and physics-based responses of vegetation. The advancement of modern GPU and recent algorithms for vegetation modeling allowed realistic and interactive modeling and simulation of plants at scales and geometric details that were not possible before.

The purpose of this bilateral project is to combine the approaches in order to develop new pruning optimization software that would not only be used as a teaching tool but also a pruning recommendation system for seasoned fruit growers who want to improve their pruning techniques. To achieve that, we have to integrate tree physiology knowledge collected over long-time observations into EduAPPLE and develop a pruning recommendation system based on criteria resulting from this new knowledge. The expected results would provide a novel approach in the training of apple tree pruning to all those who would like to acquire pruning knowledge in order to ensure local fruit source from their gardens, as well as the virtual assistant to all those who want to optimize apple tree pruning in their orchards.

In the scope of the collaboration, we developed a new two-step algorithm for dormant apple tree pruning. In the first step, the tree is shaped into one of the predefined primary forms, e.g. cone or cylinder. After that, the Discrete Differential Evolution is used to additionally remove the branches and optimize the tree light intake in the process. The algorithm has been tested on virtual trees inside EduAPPLE simulator.

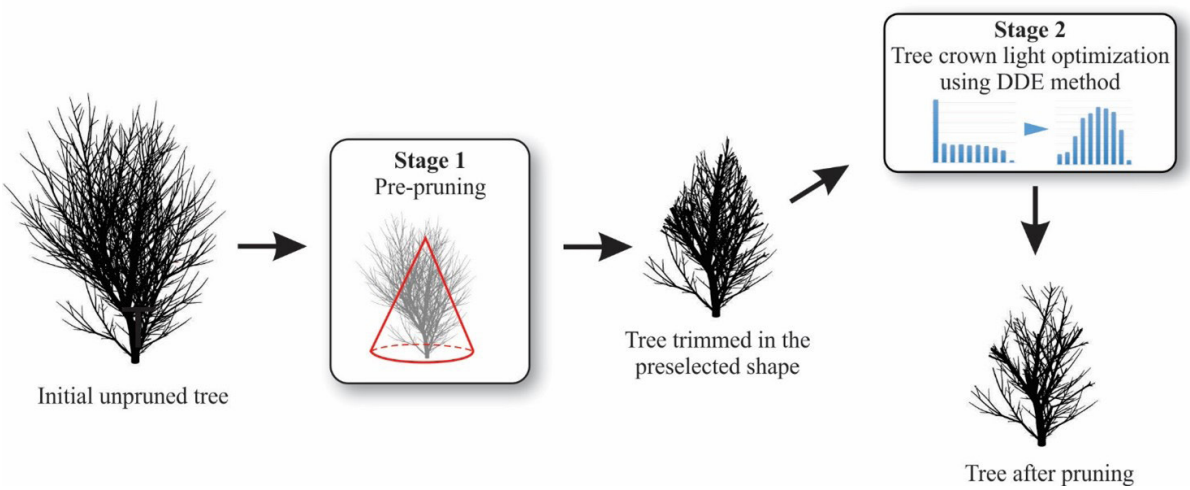



**Figure 41: Two-step virtual pruning process giving the control over tree height and neighboring distance. (Source: own)**

Unlike related algorithms based on Differential evolution, our algorithm is capable of preserving distance between neighboring trees in the orchard, and it can control the tree height as well. The simulation inside EduAPPLE showed that the developed algorithm is capable of autonomous tree training towards desirable growing form by pruning the trees over a period of time.

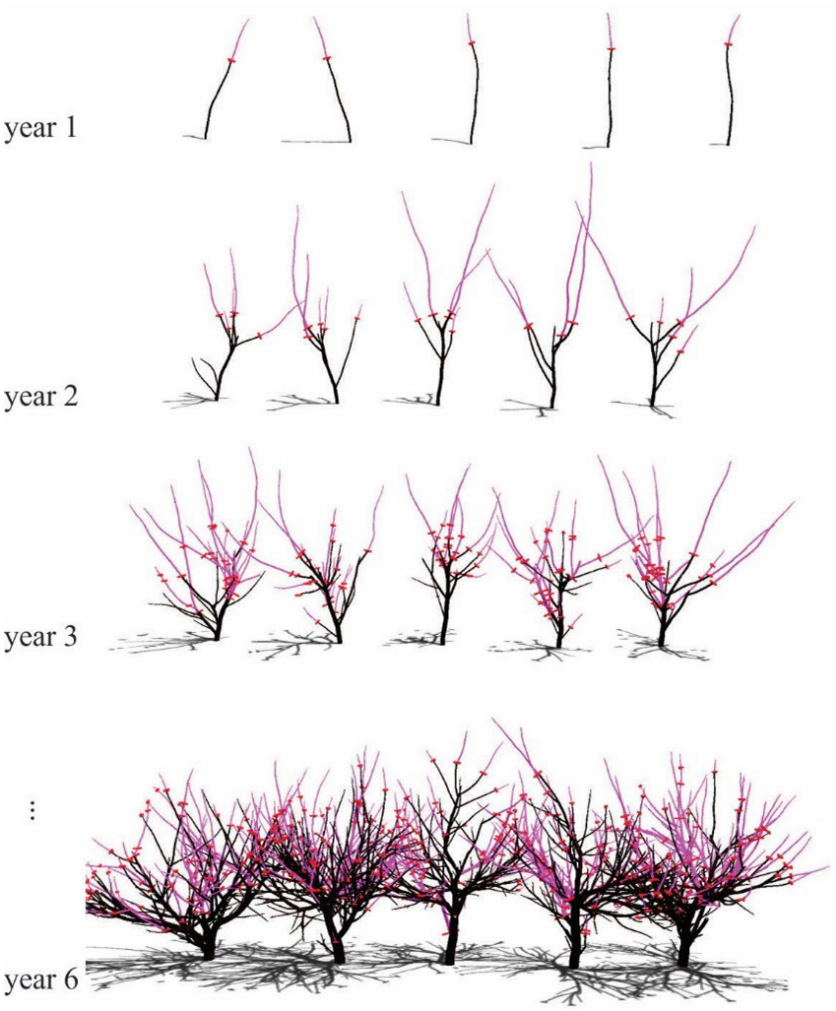



**Figure 42: Tree training of five apple trees into a Slender Spindle growing form for six consecutive years. (Source: own)**

# Research on Intelligent Early Warning of Emergency from Perspective of Public Security

Outline of national development plan for science and technology in medium- and long-term points out that public security is the cornerstone of national security and social stability. We are facing big public security threat in China, which proposes important strategic requirements for science and technology. To cope with this challenge, our government needs to construct one technology system of public security to prevent or control the emergency and adopt efficient response effectively. To bring about a multi-functions integrated emergency guarantee pattern with information and intelligence technology application as the leader, this system will help our government to strengthen its capability of dealing emergencies with rapid response and by predicting sudden events scientifically. From the perspective of public safety, this project utilizes video data captured by cameras installed in public areas and does **early warning for crowd abnormal activities,** as well as providing service for **public safety of ethnic minority areas**.

Although there are many important research theories and applications in video behavior recognition in recent years, but there are only a limited number of research works related abnormal behavior based emergency from perspective of public security, especially for the performance of real-time or robustness of abnormal crowd behaviors recognition algorithms. There is still a lot of research work to do in early warning for sudden group abnormal behavior. In the figure below a prototype system example developed within the project is shown, where pedestrians are detected by using convolutional neural networks (CNN) deep learning approach.

### Financed by

ARRS – Slovenian Research Agency (contract BI–CN/18–20–0001)

### Duration

2018 to 2020

### Partners

UM Faculty of Electrical Engineering and Computer Science, Dalian Minzu University, China

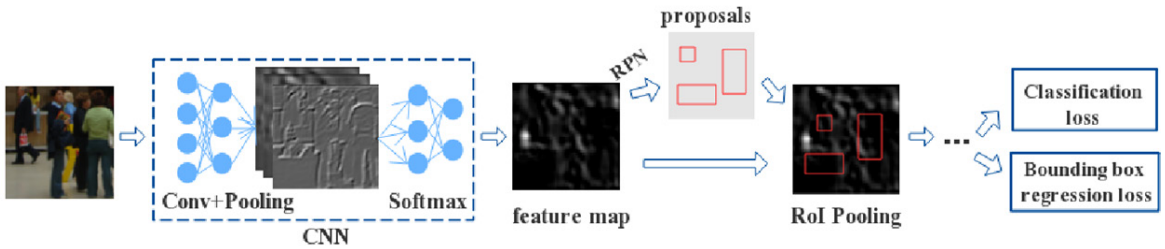



**Figure 43: Developed approach for pedestrian detection using CNN (Source: S. Liu et al., Pedestrian Detection based on Faster R-CNN International Journal of Performability Engineering, 15 (7), pp. 1792, 2019).**

# Hologram Representation of Cultural Heritage

## Financed by

ARRS – Slovenian Research Agency (contract BI–BA/1920–003)

## Duration

2019 to 2020

## Partners

UM Faculty of Electrical Engineering and Computer Science, University of Sarajevo, Bosnia and Herzegovina

Curators of museums, archaeological sites, architectural and other cultural monuments became conscious, decades ago already, of capabilities of digital technologies to improve perception of cultural heritage (CH) among visitors of such sites and to enable the perception to interested remote audience. Many artefacts are not permanently available to visitors due to the lack of exhibition space, restoration work, or the artefacts' fragility. Digital technologies may also reassemble broken or otherwise damaged CH monuments, supplement them with the missing (virtual) parts, and embed them in a wider historical context. They also enable fast and safe exchange of contents among distinct institutions, both in a form of visiting virtual exhibitions or for completion of their own material collections with reasonably related digital contents. The digitalisation and visualisation of CH thus represent important stimulators for further progress of spatial data capture and modelling, computer graphics, virtual and augmented reality, human-computer interaction and digital multimedia. Through the previous cooperation, both groups focussed on geometric modelling, interaction with virtual environments and spatial data input. This time, the partners aimed to address the visualisation of the digitalised CH. The visitors of CH sites are usually not satisfied with traditional visualisation technologies. They expect richer 3D experience through alternative output devices and new ways of interaction. In this project, the challenges of utilisation of holographic pyramids in applications of CH visualisation were addressed. Though these devices do not provide real holograms but only a hologram-like visual illusion, the technology gained huge popularity. Miniaturised implementation, usually combined with a mobile device, is easily accessible to everyone, while bigger professional installations may elegantly, attractively and functionally supplement the museum interior due to their futuristic shape and particularly the created 3D illusion. UM FERI has detected some open challenges related to the preparation of digitalised contents, design of the device as a whole, its hardware and optical components in order to increase the realism of created illusions. ETF Sarajevo (Faculty of Electrical Engineering, University of Sarajevo) utilized its knowledge and practical experience with the CH visualisation, performed studies of user requirements and analyses of user experience in order to set up the directions for validation of the considered technological solutions. We also assessed particular experimental installations regarding the set directions. Particular challenges within preparation of data were projected in the holographic pyramid comprising inclusion of bigger scenes, background, terrain and avatars (3D human models which guide a visitor through the virtual environment, talk stories about the artefacts etc.). Namely the contents to be displayed in holographic pyramids are usually prepared in a manner to produce an illusion of a single object floating within the pyramid. There are eventually several smaller objects displayed, but they are still positioned in a manner providing the projection to the middle of the pyramid. However, a wider context is usually desired when the CH is being considered.

**Figure 44: Interactive control of the digitized Roman artefact, found in Balkan area in holographic pyramid with the use of Leap motion sensor. (Source: own)**

Thus, an object should placed in a concrete space, onto the terrain, next to other objects and in front of the background representing its original historical location. We also prefer an avatar somewhere in the peripheral part of the pyramid as it is aimed to supplement the exhibited artefact and not to obstruct or substitute it. A part of the UM FERI group deals with the construction of holographic pyramids. The listed challenges shall, thus, be also addressed through experimenting with different organisations of optical components and with utilisation of various materials with diverse optical characteristics. The holographic pyramids for the so-called integral photography are often used as an alternative to the regular holographic pyramids. The research group from ETF Sarajevo provided adequate geometric models to be visualised within the pyramids, and also assessed the user experience due to the determined goals and criteria. A user experience obtained through organisation of the scene into a system of multiple holographic pyramids or by combining the pyramids with other elements of immersive environments, narration and scenography may also represent an interesting challenge. The interaction also plays an important role in achieving the overall user experience. To support eventual future complete system implementation, we also studied the manipulation of represented contents with manifold technologies of virtual and augmented reality.

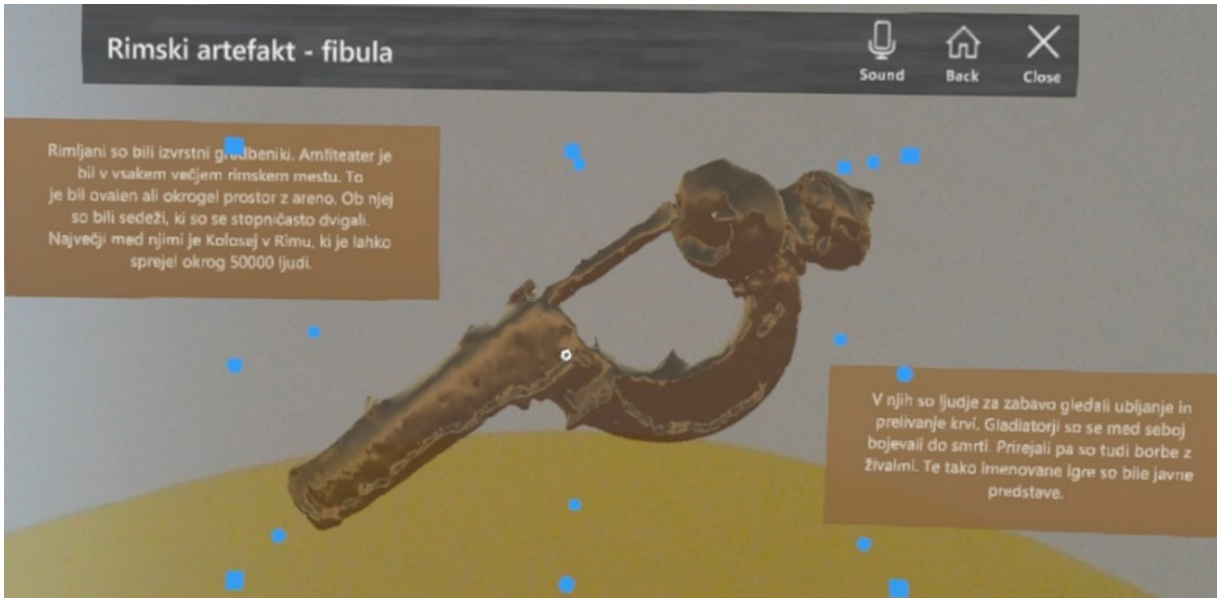



**Figure 45: Digitized Roman artefact, found in Balkan area, visualised, and controlled through Microsoft HoloLens glasses. (Source: own)**

# Analysis of Internet-based Cultural Transmission by Knowledge Graphs

Data mining algorithms are becoming important for the analysis of big data such as social networks graphs, where cultural transmission is one of the semantic components. One of the exciting new algorithms are based on knowledge graphs, which were firstly proposed by Google in 2012. Knowledge graph generally refers to an algorithm for constructing a subgraph representing semantic relation network. Currently most of the researches focus on the theoretical research of culture transmission, or on the algorithmic aspects of knowledge graph construction. Few scholars combine the two aspects, in order to study how to realize the sustainable development of culture transmission. Based on the cross media big data of culture transmission, this project fully takes the advantages of big data mining and parallel computing technology. The aim would be based on construction of knowledge graphs of culture transmission and extraction of public interest points. Relying on big data parallel computing technology, we will enhance the performance of **cultural transmission analysis**.

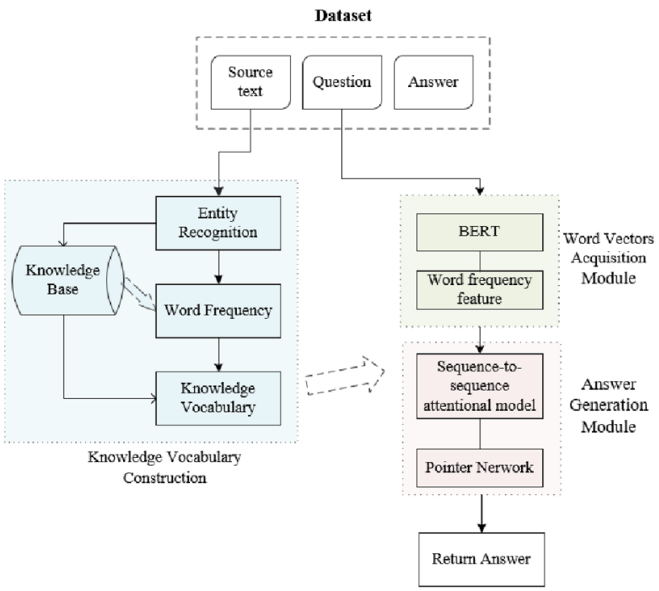



**Figure 46: Automatic answering system based on knowledge graph (Source: S. Liu et al., Research on Automatic Question Answering of Generative Knowledge Graph Based on Pointer Network, Information, 12.3, 136, 2021).**

## Financed by

ARRS – Slovenian Research Agency (contract BI–CN/20–21–20)

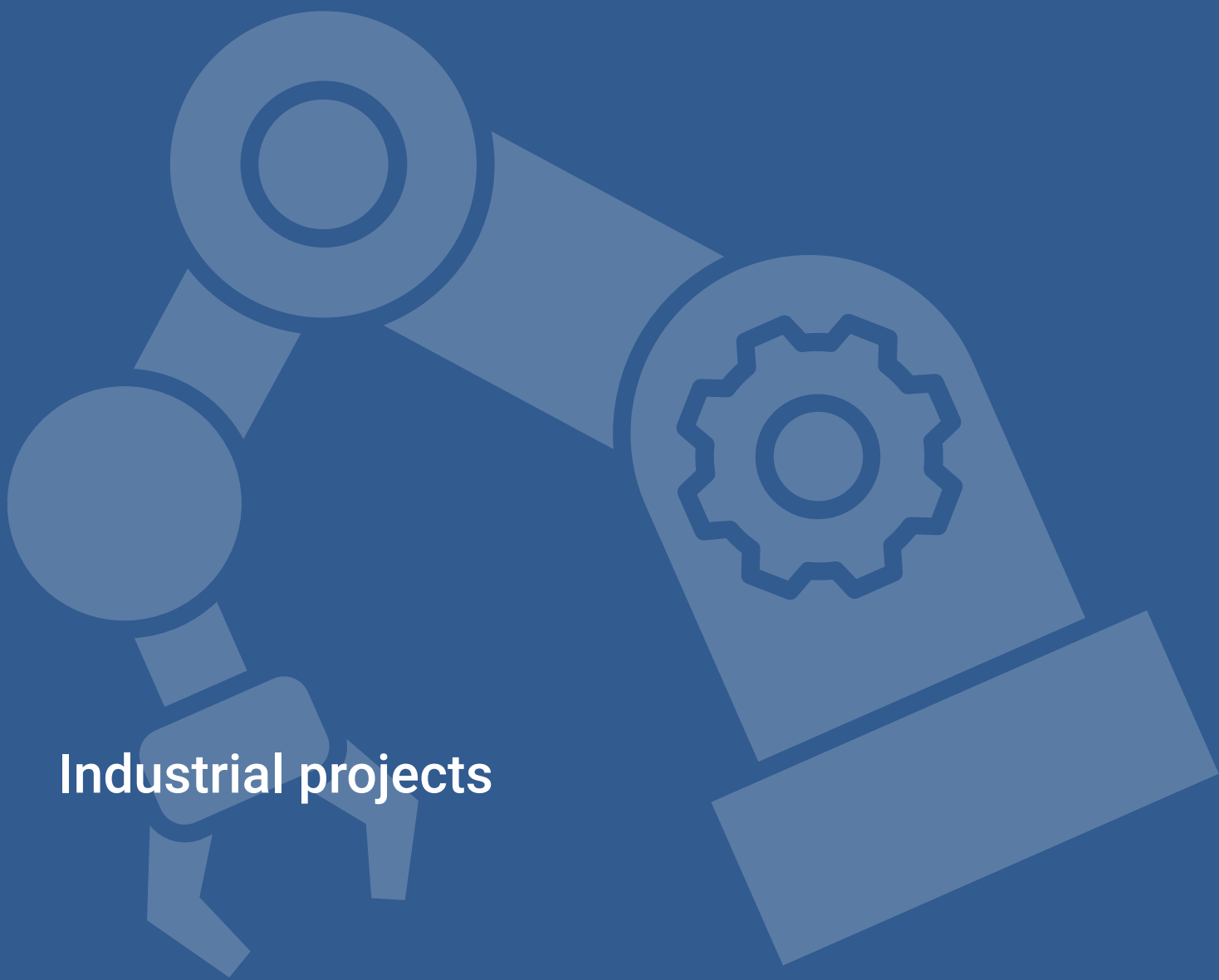
## Duration

2020 to 2021

## Partners

UM Faculty of Electrical Engineering and Computer Science, Dalian Minzu University, China

The project will also have social impacts beyond the scope of the project, by disseminating the attraction of internet-based cultural transmission, while demonstrating the influence of Chinese and Slovene cultures algorithms. In the figure on the left, the developed methodology is shown, where knowledge graph is constructed from source texts, and then used in answering generation module.



# Industrial projects

# TunePerfect

Goal of the project was to develop simple **UI/UX for self-fitting of the hearing aid devices** as an alternative to the audiologist driven fitting approach. This was achieved by grid based user exploration where users can boost hearing aids' frequency gains (EQ) by navigating though the presented grid which on interaction temporarily applies EQ directly to the connected hearing aid. Therefore, by exploring the grid matrix, one can adjust properties of the hearing aid device and find optimal hearing for the provided audio samples. User is guided through 4 different steps where first step sets the global EQ curve and other steps serve as fine tuning of the EQ.

Our involvement with the project was to develop:

- **Friendly interactive tutorial** which guides users through self-fitting process;
- **Tool that enables 3rd parties to translate** every aspect of the application **into their desired language**;
- **Tool that performs analysis** based on TunePerfect usage telemetry and **visualizes user interaction** with the software in form of heatmap which enables further UX adjustments.

## Financed by

Altran Switzerland AG

## Duration

2016 to 2017

## Partners

UM Faculty of Electrical Engineering and Computer Science, CwIT s.p.

## Additional information

http://audioap.ciopro.si/

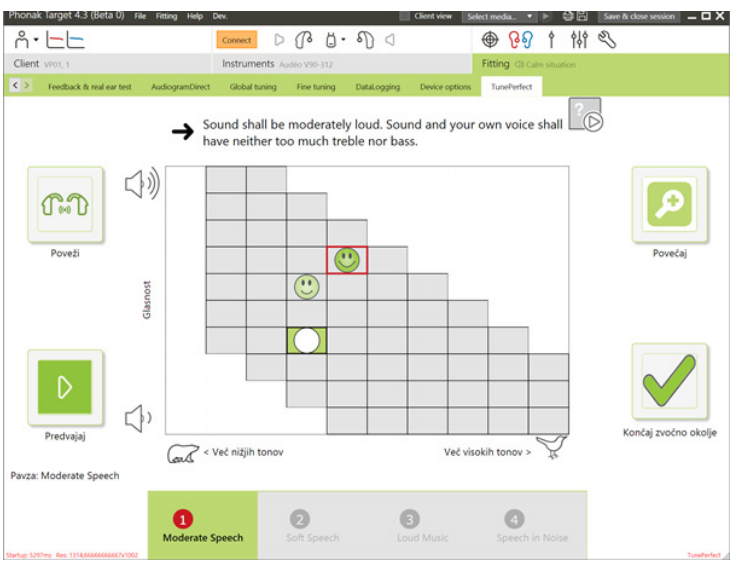



**Figure 47: TunePerfect integrated into PhonakTarget application developed by Sonova. (Source: own)**

# Design of the Information Support for Vegetation Management in the Power-line Corridors

**Financed by**

ELES d.o.o.

**Duration**

2017 to 2018

Vegetation poses a danger to power lines, as trees can fall on them. Therefore, it is needed to perform periodic inspection of vegetation and perform appropriate actions. The aim of this study was the development of a plan for an **automated vegetation management system** and its integration into the existing information system for the Slovenian Electricity Transmission System Operator – ELES.

The most important functionalities of the system are the following:

- Detection of trees;
- Transparent management of vegetation data and restrictions for taking actions on the vegetation;
- Forecasting the vegetation development;
- Support for planning measures and tools for analysis and reporting on vegetation management workflow.

On the basis of the survey of remote sensing technologies, possible ways of using them for the implementation of the predicted functionalities of the vegetation management system were proposed. The study proposed a separate vegetation management module that connects with the existing components of the information system through existing databases and common data structures. Finally, the study provided an estimate of the costs and benefits of the potential introduction of the vegetation management system.

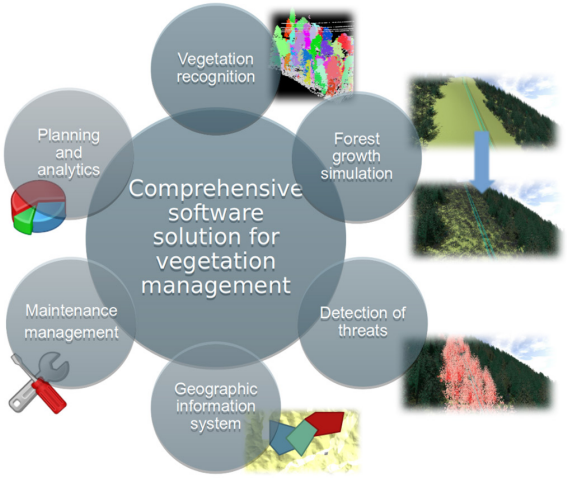



**Figure 48: Components of the information system for vegetation management on transmission line corridors. (Source: own)**

# Development of Geoinformation Systems, Services and Solutions

The aim of the project was the development of the geoinformation systems and services, which are divided in these three areas:

- Development of algorithms, libraries and visualizations for use in Java application for editing geometric objects, which are stored in the relational database Oracle 12c and accessed through the spatial infrastructure (Geoserver) and dedicated REST services in the form of GeoJSON and TopoJSON. Editing of geometric objects (point, line, polygon, polyline and multipolygon) is performed in the way of minimal changes and optimized geometry construction on server and client side with traceability of changes provided (versions of geometric objects);
- Development and upgrades of system tools with INSPIRE development guidelines for the management of metadata structures and descriptions of spatial and descriptive data based on open-source solutions Geonetwork and Re3gistry (shown on image bellow).;
- Development of tools for monitoring and managing data flows of heterogeneous sensor systems.

**Financed by**

Igea d.o.o.

**Duration**

2018 to 2021

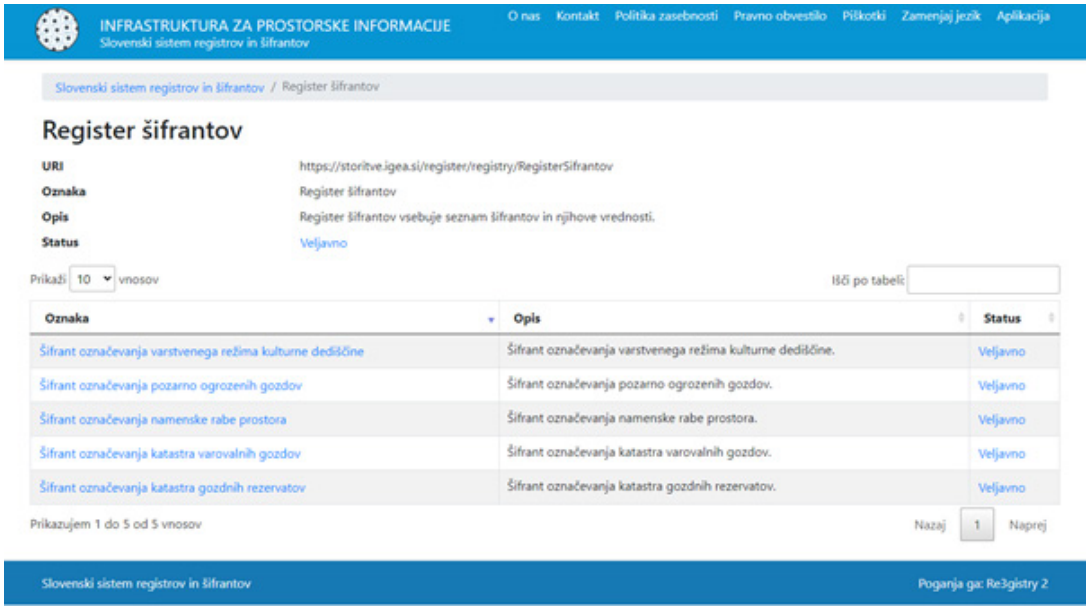



**Figure 49: Slovenian system of registries and codelists. (Source: own)**

# Advanced Visualization Components

**Financed by**

DEWESoft d.o.o.

**Duration**

2018 to 2022

GEMMA has collaborated with the DEWESoft company and developed **advanced solutions for transfer and 2D/3D visualization of geographic data based** on OGC standards. These solutions were integrated into DEWESoft software as custom visual controls which implement the necessary interfaces to be consumed by the application. Developed solution enables users to **synchronize geolocated measurements on 2D or 3D map** (e.g. real-time tracking of transport vehicles), insertion of custom 3D models, and tracking of different vector or scalar parameters (e.g. color-mapping the visual track based on velocity change).

After successful release and positive feedback of map component, demand for aviation features increased, resulting in 3D terrain support and standalone 3D model visual control. New control can be used for aircraft orientation visualization without need for the geographic location. Furthermore, Map component was upgraded to support the real-time LiDAR data visualization from mounted hardware.

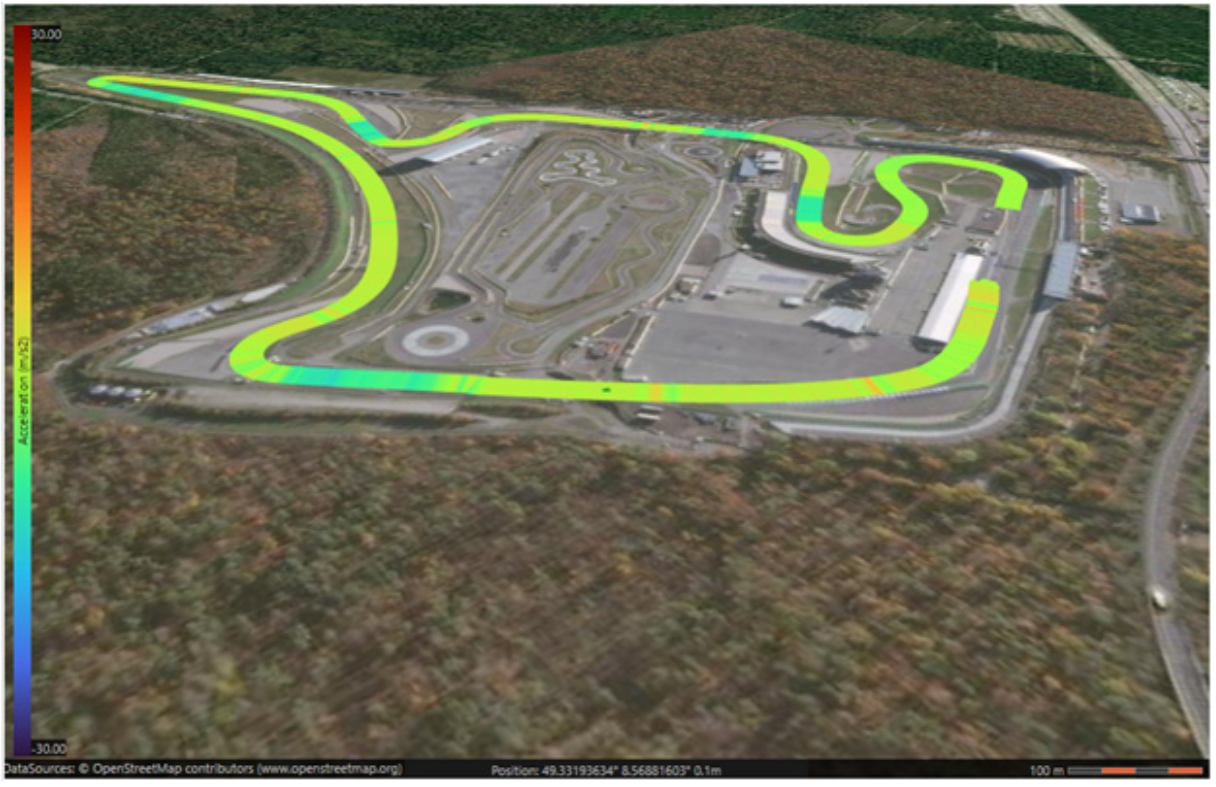



**Figure 50: 3D Map of the Hockenheimring racing track. (Source: own)**

**Figure 51: 3D map with terrain details and 3D model visual controls overlayed on top of each other. (Source: own)**

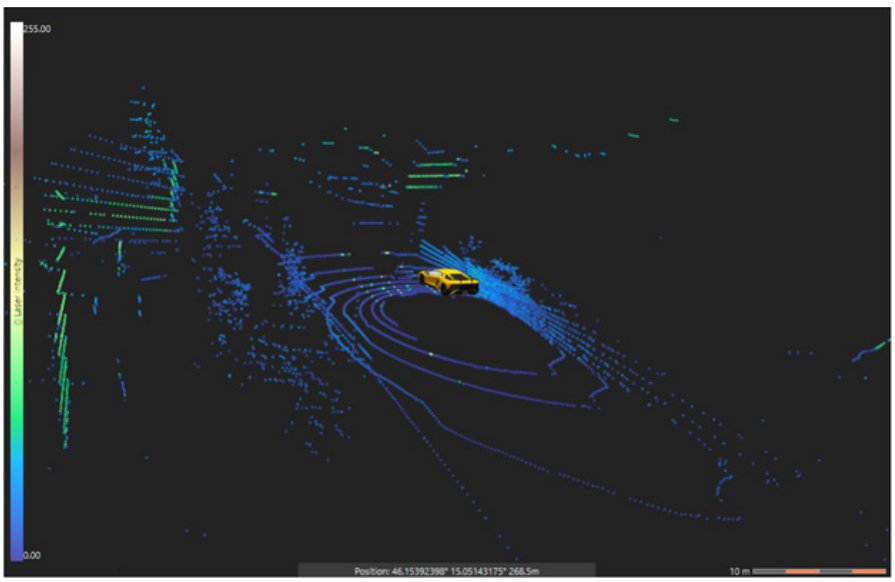


**Figure 52: Real-time LiDAR data visualization without active map layers and selected 3D car model. (Source: own)**

Since then, GeMMA also shifted to the non-geospatial fields of expertise and helped to improve the existing visual control for the modal geometry which is indispensable tool for understanding the vibration aspect of mechanical structures through visualization and animation. Geometry can either be loaded from standard UNV file format or created manually in geometry editor, where vertices can be mapped to the real measurement data in order to animate entire structure. Moreover, the textbox widget was developed, which supports rich text formatting capabilities and allows for custom user annotations anywhere on the screen. Additionally, it supports user expressions for displaying real-time values and properties from the data channels.

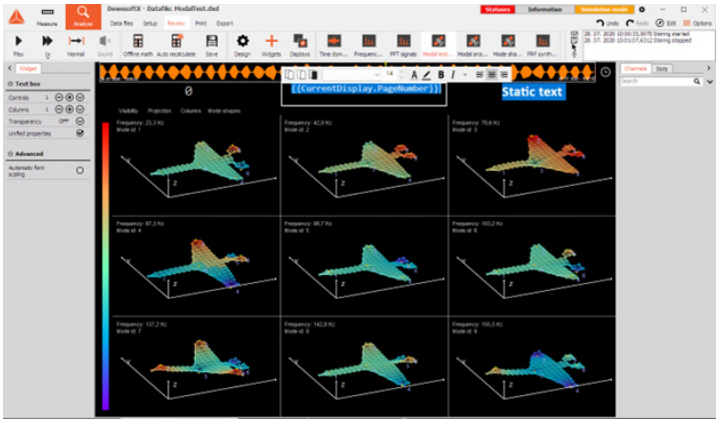



**Figure 53: Modal geometry and text widget in DEWESoft software. (Source: own)**

Additional widgets to help with the time domain and frequency domain data visualization were also developed to be used together with orbit analysis module that is used for vibration analysis of rotating machinery.

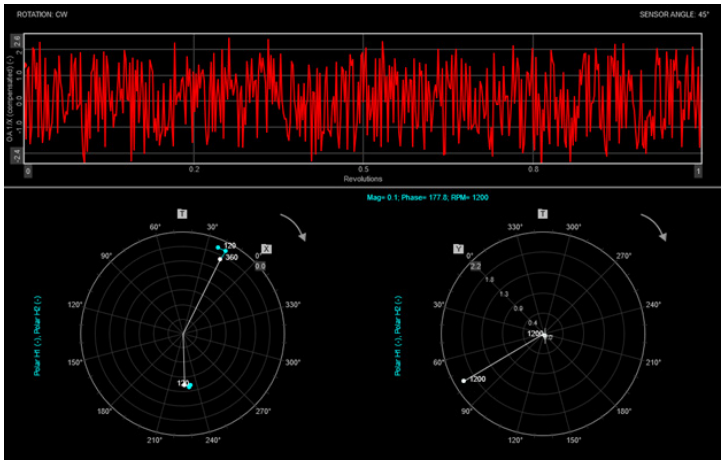



**Figure 54: Waveform graph and polar plot widgets used with orbit analysis module outputs. (Source: own)**

Up till 2022, GeMMA lab. was involved in the development of 9 different visual controls, which are part of the core package and is actively contributing to the DEWESoft core software by improving its 3D graphics engine using DirectX graphics library.

# ORYX – Massage Roller Control Application

Mobile application for controlling Bluetooth® enabled Relaxroll devices. Connect your Relaxroll devices, start a routine, and let the application do the thinking and just relax. Tap into curated routines and enjoy automated speed setting control.

ORYX is a foam massage roller with integrated Bluetooth® chip for communication with other devices. The aim was to develop a frontend and backend application to control smart wellness devices.

The application is able to:

- Notify the user for recovery sessions;
- Suggest a predefined recovery session;
- Connect to smart devices;
- Changning speeds of the connected device;
- 3rd party connectivity.

**Financed by**

Relaxroll Gmbh

**Duration**

2019

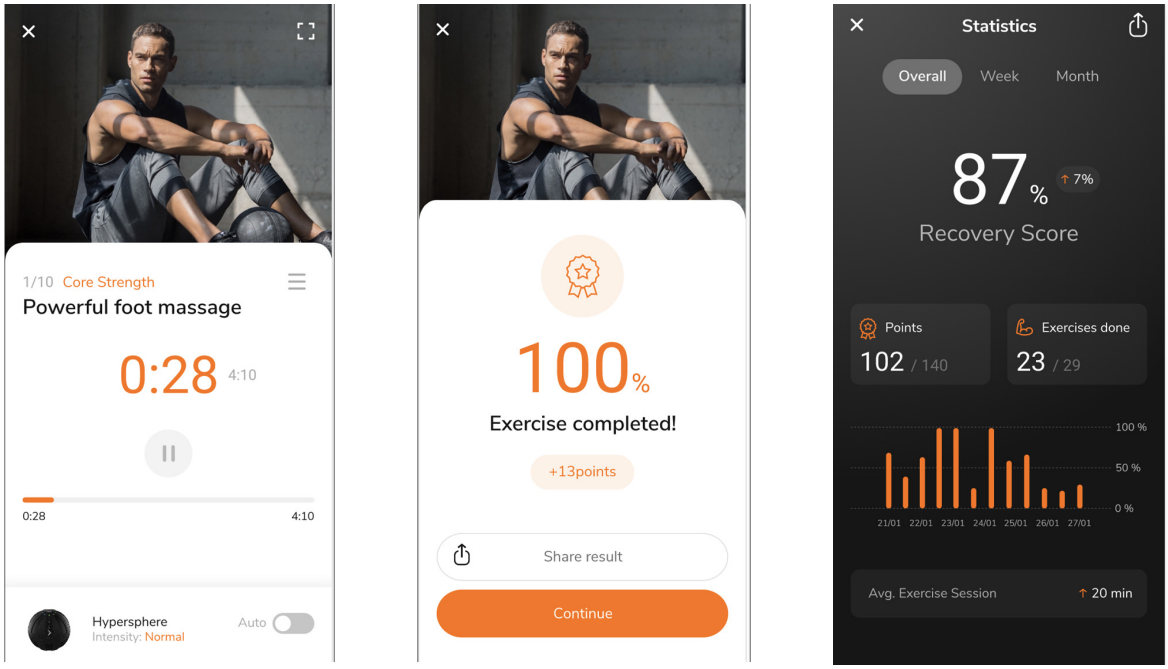



**Figure 55: Oryx application. (Source: own)**

# Advanced Investigation Platform

**Financed by**

MNZ RS, Police

**Duration**

2019

The Advanced Investigation Platform (AIP) allows the user to search and analyse patterns in big network data. The entire platform consists of four core levels, namely:

- Presentation;
- Application;
- Logic;
- Data levels.

The presentation level consists of a web application that allows a user to define simple and advanced queries via the user interface, or directly using a script.

The web application also supports the visualisation of query results, and highlights a set of functionalities from the application level in a user-friendly way. It implements an Application Programming Interface (API) between the user and the logical layer in the form of REST service queries. The logical level of the platform consists of data level access, security, authorisation, authentication, algorithms for statistical analysis and finding correlations in data samples, and support for adding various external services that enable scalability of the platform (e.g. mapping between arbitrary data formats). The data layer consists of various encrypted databases, such as a user database, a database of networks, a database of registered plug-ins, a database for replicating and buffering query results, and a database for storing analytical results.

# Development of an Application for Interactive Presentation of Museum Exhibitions

Within the laboratory, we developed an application for the interactive presentation of the exhibits of the museum collection. The application serves as the innovative replacement for traditional info panels usually accompanying the exhibitions. Instead of a classical static presentation, the application enables the presentation to be broken into a series of stories bound to the exhibit, which the visitor can browse through. Each story is centered around the photograph, or a picture displayed in a special bar next to the exhibit's description. The entire collection is represented with images displayed in one or more image stripes. The corresponding database and module for data entry support the application. The application is a part of the permanent exhibition titled Spaces of the beautiful in Maribor Regional Museum.

**Financed by**

Maribor Regional Museum

**Duration**

2020

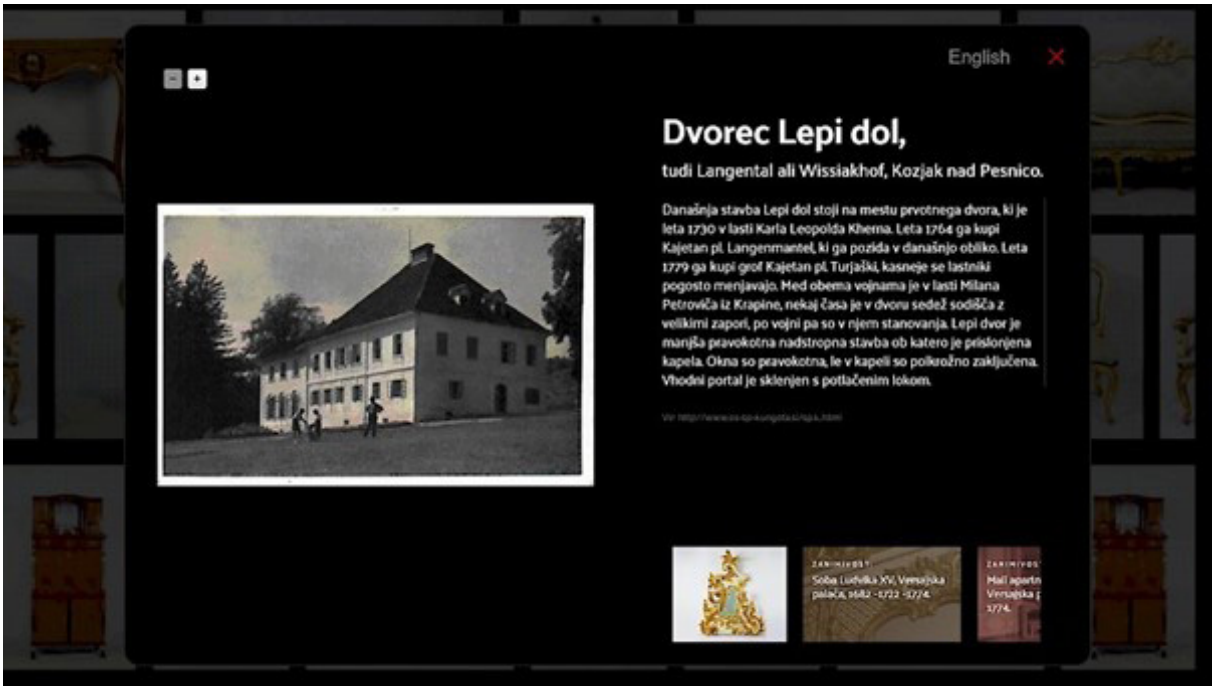



**Figure 56: Photograph and description of the exhibition object, together with related objects within the Application for Interactive Presentation of Exhibits in the Museum Collection. (Source: own)**

# Proposal for the Development Plan of the Spatial Data Infrastructure of the Municipality of Maribor

**Financed by**

Municipality of Maribor

**Duration**

2020 to 2021

The purpose of the MOM (Municipality of Maribor) Spatial Data Infrastructure Development Plan is:

- Guidelines for individual projects and investments in spatial data infrastructure for the needs of municipal authorities, funds, urban districts and local communities, as well as public utilities and public institutes;
- Coordinated implementation of projects for the establishment of spatial data and the development of information equipment;
- Organizational chart in which the actors, their roles and duties will be identified, which will be the basis for the organization of the field.

The following activities were carried out:

- Preparation of materials and conducting interviews;
- Analysis of the situation, needs and development plans by departments of the city administration and public service providers and other users of spatial data and services;
- Analysis of trends and needs arising from the SUS (Sustainable Urban Strategy), the Smart City of Maribor initiative, the national project e-space and legislation (emphasis on ZUreP-2, GZ, Environmental Protection Act) and at least one case from abroad;
- Proposal of the plan for the development of the spatial data infrastructure of the Municipality of Maribor;
- Preparation of materials and implementation of workshops with representatives of the Municipality of Maribor.

# Research and Development of Geoinformation Systems, Services and Support Algorithms

The goal of this project was the development of information systems, services and solutions using the EMRIS (Unique Methodology of Development of Information Systems) methodologies and agile methods.

This Includes:

- Development of java libraries and specific REST services for processing and visualization of GeoJSON and TopoJSON data, as well as optimized storage in the Oracle 12c database using the GeoServer spatial infrastructure;
- Development of algorithms for geometrical object editing based on »minimal change« paradigm;
- Development of optimized algorithms for tracking data change on the server and on client side;
- Development of tools for managing metadata using the INSPIRE guidelines based on opensource tools GeoNetwork and Re3gistry;
- Development of libraries for spatial raster data processing;
- Development of tools for processing of data streams from sensory systems.

**Financed by**

Igea d.o.o.

**Duration**

2021 to 2022

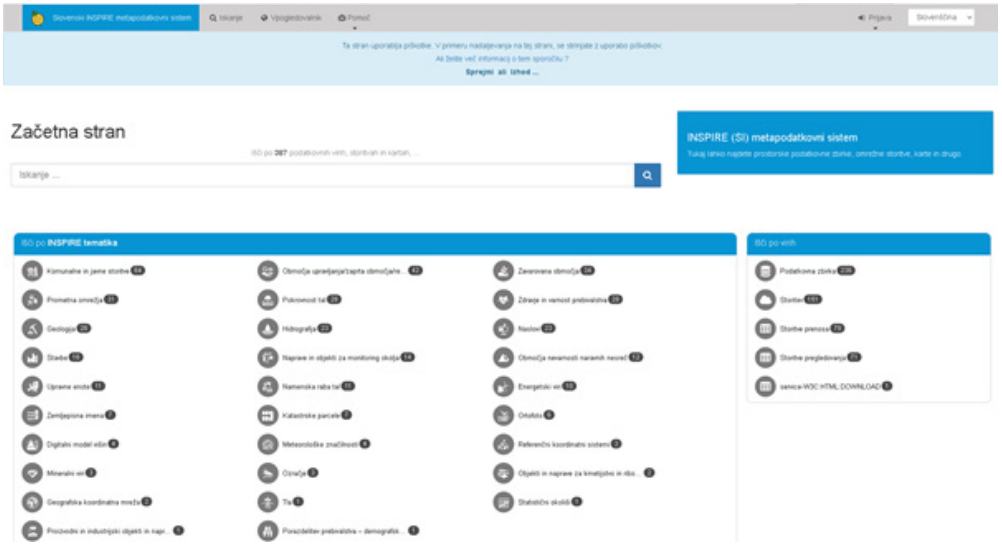



**Figure 57: Slovenian INSPIRE Data Portal. (Source: own)**

# VegeLine – Information System for Risk Assessment and Vegetation Management inside Powerline Corridors

## Financed by

ELES d.o.o.

## Duration

2021 to 2022

## Partners

UM Faculty of Electrical Engineering and Computer Science, Troia d.o.o., Inova IT d.o.o.

Project goal was to develop and deploy **information system for risk assessment and vegetation management** which aims to reduce manual terrain surveying and increase long-term planning efficiency for vegetation clearance inside powerline corridors. Main objective was to **detect critical areas and prevent risk** of the potential network outages caused by excessive vegetation growth, with secondary ideal to **optimize for lower operational costs** of the internal and external vegetation management services. Overall, the goal was to **improve planning efficiency of the vegetation clearance schedules** over longer time periods.

The main functionalities of the developed information system are calculation of the vegetation growth based on predictive canopy growth models, detected risk areas, and algorithms for intervention optimizations based on estimated operational costs.

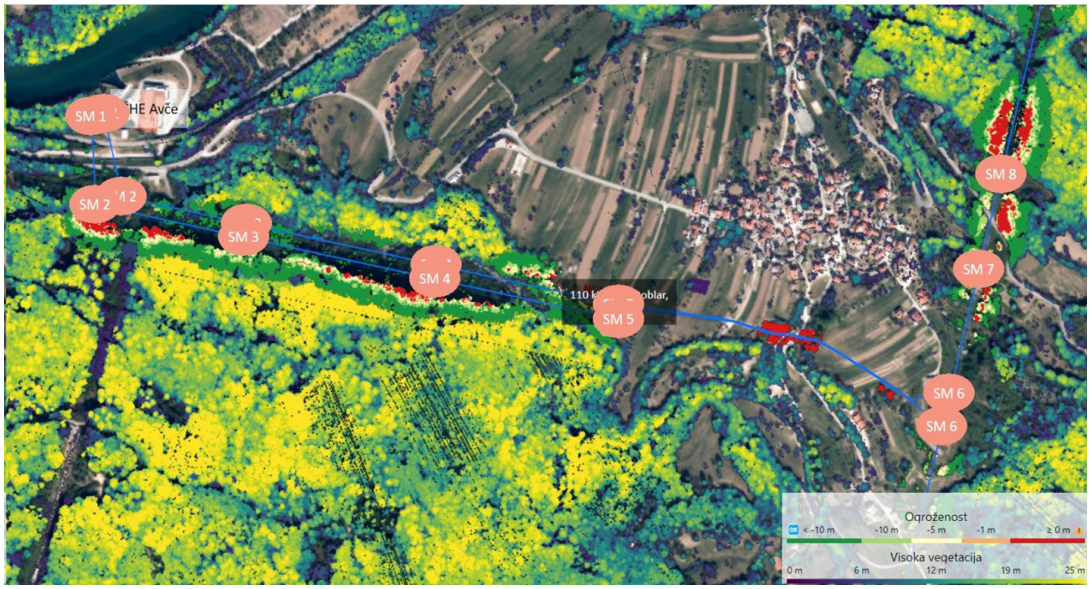



**Figure 58: Visualization of the spatial layers produced by the vegetation management system. (Source: own)**

To yield mentioned results, the system incorporates wide range of available spatial data from integrated first party services in form of temporal LiDAR scans, powerline networks, protected areas for species and habitats preservations, and environmental data such as amount of precipitation, air temperature, sunshine duration, and soil qualities. System then automatically produces and derives necessary products such as digital terrain and canopy height models, spatial filters which define maximum vegetation heights, and outputs of the vegetation growth simulations. Derived data is required for further processing and decision making and results of the system are detailed risk assessments and clearance plans which aim to minimize operational costs. System exposes those results in form of standardized services and formats which are then consumed from within existing IBM Maximo asset management system and ESRI ArcGIS. Moreover, advanced client tools were developed for system administration, data-source management, raw data editing, visual data analytics and detailed intervention planning capabilities.

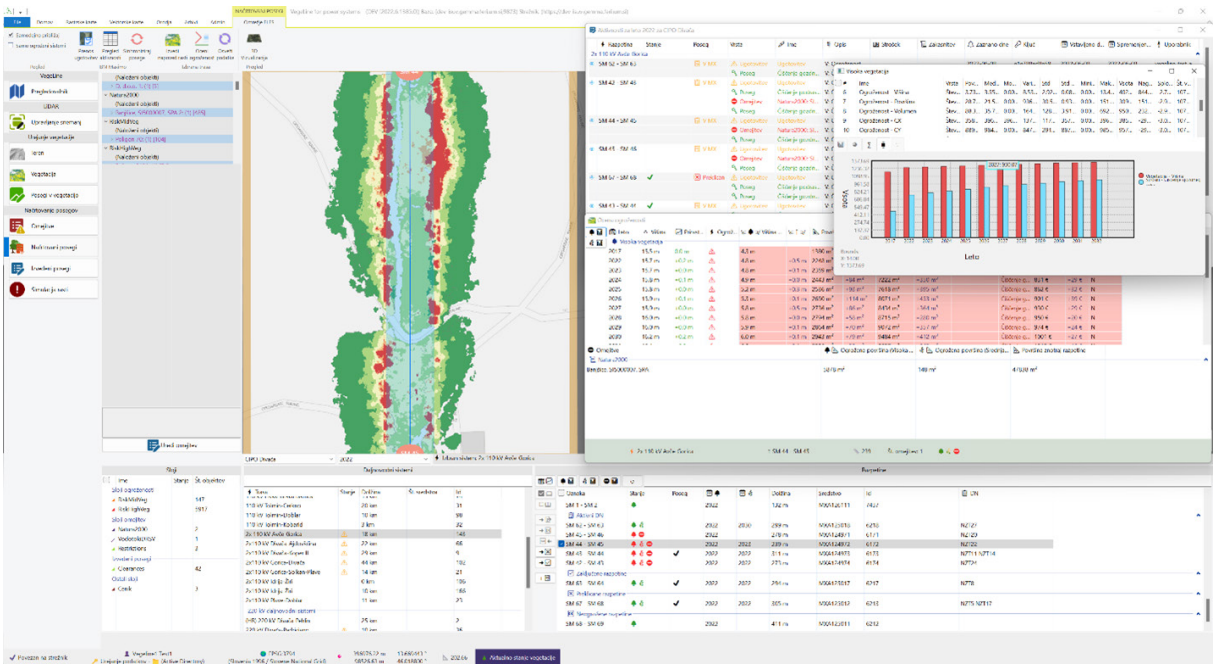


**Figure 59: Risk assessment and tree growth predictions for 10 years into the future on the selected powerline span. (Source: own)**

# Assessment of the Photovoltaic Potential of Pošta Slovenije's Real Estate Facilities

**Financed by**

Pošta Slovenije d.o.o.

**Duration**

2021

This is an R&D project financed by Pošta Slovenije d.o.o., where **Laboratory for power engineering** at UM FERI jointly collaborated with the GEMMA lab. The project provided an insight into photovoltaic capacity of Pošta Slovenije's real estate facilities. Due to a high number of facilities the financer required a systematic overview of **photovoltaic potential assessment** to support decisions regarding the investment into photovoltaic systems. An automatic system for generating reports regarding the assessment of photovoltaic potential of any building in Slovenia was developed. The system automatically obtains LiDAR data from a public database and processes it for each location to take shadowing from surroundings into account. The measurements of direct and diffuse radiation from the closest meteorological stations of each location were used for the calculation of solar radiation. The reports include general information of each real estate, mapped influences of each considered assessment factors (aspect, inclination, shadowing, …), solar potential and photovoltaic potential. For the assessment of photovoltaic potential the characteristics of three solar panels that were provided by the financer were considered. In addition to the dimensions of solar panels, the non-linear characteristics that affect efficiency in relation to the received radiation were considered at an hourly time step. The electricity production was provided on a monthly level for each type of panel as shown in the figure below.

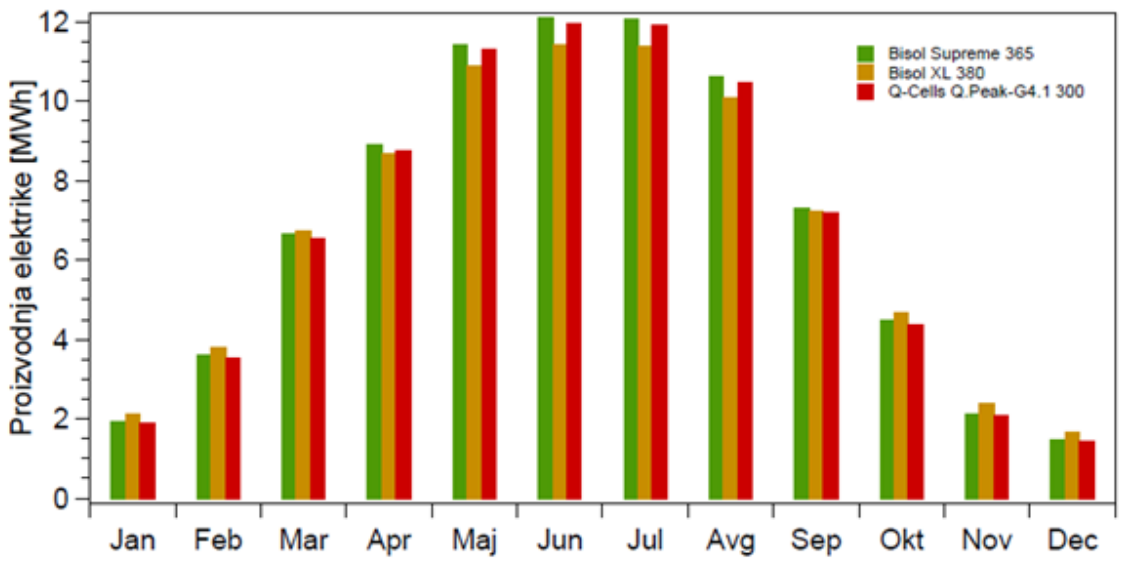



**Figure 60: Monthly electricity production for a selected real estate facility. (Source: own)**

The photovoltaic potential was first given for a case when the whole roof would be used for solar panel installation as a measure for total capacity. The maximum capacity was given as rated power and estimated using the number of possible installations of solar panels in regard to the dimensions of each panel. Additional case for improved return of investment was provided by excluding the highly shaded roof areas, as shown in the following figure.

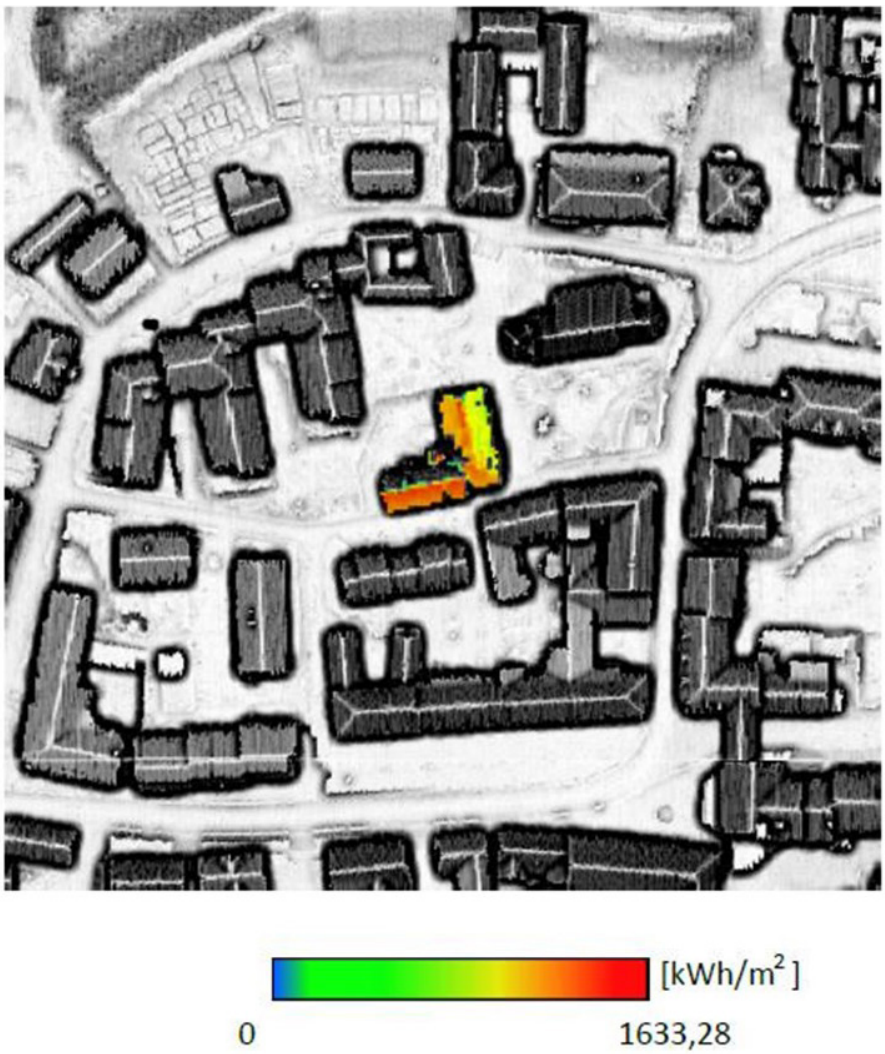



**Figure 61: A selected real estate's received solar radiation for a case with excluded highly shaded roof. (Source: own)**

# Architecture and Interoperability Management Plan for Spatial Information

## Financed by

MOP RS, The Surveying and mapping Authority of the Republic of Slovenia

## Duration

2021 to 2022

The Ministry of the Environment and Spatial Planning (MOP) is the holder of a multitude of spatial data within the state infrastructure, as it manages over one hundred databases in the field of space, environment, nature, water and real estate, which serve as a source of reference for other users, however, it is not the only manager and provider of spatial data. Within the Ministry, there are different areas of work within the directorates, offices, agencies and constituent bodies. As a result, various internal and external data flows are emerging, both internally and nationally, as well as in interaction with the EU (eg environmental reporting, INSPIRE-2 transfer).

From the point of view of information architecture, organization of informatics and spatial data infrastructure, there is no single, validated model that would provide effective support within the ministry for future information society requirements and upcoming projects within the ministry and wider at the national level. This project provided guidelines and a plan for the establishment of an **internal infrastructure for the management of spatial data of the Ministry**, as well as guidelines and a plan for the establishment of a **common national spatial infrastructure.** In other words, the project provided a **blueprint for the implementation of dataspace in the geospatial domain**.

The technical guidelines and the establishment plan was based on existing strategic and implementation documents created in the field of spatial information management, which seek to identify gaps that arise in the implementation of integration in the future. The purpose of the document was to get acquainted with some trends and variants of solutions and concepts that ensure the stable operation of the infrastructure in the future in accordance with the areas of application.

The project also resulted in the analysis of options for providing information infrastructure and the development of a plan for the establishment of a common spatial information infrastructure of the Ministry of the Environment in the field of space, environment, nature, water and real estate.

As a result we proposed an organizational and information architecture that the Republic of Slovenia could use in developing and strengthening its approaches to national spatial information management. A plan for the establishment of a common spatial information infrastructure in Slovenia was prepared, with special emphasis on the processes and activities within the competence of the Ministry of the Environment and Spatial Planning. The project work resulted in substantive, organizational and technical guidelines for the development and establishment of the Spatial Information Infrastructure (SII) of the MOP and the Common National Spatial Data Infrastructure at the state level.

# Short-term and Long-term Traffic Forecasting System Using Artificial Intelligence Algorithms

The purpose of the project is to create a system that will enable **advanced calculation and insight into traffic forecast** in accordance with the operational requirements of the client, based on advanced methods of artificial intelligence. In this context, the development of cloud analytical algorithms is planned, together with appropriate user applications and their integration into the operational environment of the control center. The project covers the entire motorway network in Slovenia and the most important parallel and main roads. The system will enable **short-term, medium-term and long-term forecasting** and will be designed to relieve the traffic, to increase the level of autonomy in the analysis, to supplement and improve the quality of possible automated calculations and to increase the speed of reliable forecasts.

**Financed by**

DARS d.d.

**Duration**

2021 to 2023

**Partners**

UM Faculty of Electrical Engineering and Computer Science, CreaPro d.o.o.

The following key objectives of the project can be identified as:

- Objective 1: Establish an infrastructure for the operation of traffic forecasting system applications;
- Objective 2: Establish a data model for recording a calendar of holidays in neighboring countries;
- Objective 3: Establishment of a data model and application for the collection and maintenance of data from open online sources on weather and other parameters that affect traffic;
- Objective 4: Establish a data collection and merging system to support the operation of the forecasting model;
- Objective 5: Integration of traffic meters with real-time data;
- Objective 6: Data cleansing;
- Objective 7: Implementation of a forecasting model for short-term and long-term traffic forecasts;
- Objective 8: Data export services and control application showing forecast results;
- Objective 9: Testing and implementation of the solution in production.

Within the project, GeMMa's main contributions are:

- Examination of web APIs through which relevant data for learning a prediction model is accessible;
- Preparation of server data models for the transformation of data into a format that will be suitable for their integration into the development tool and data viewer;
- Establishment of appropriate web API interfaces and data viewer for access and integration of data relevant to the forecasting model;
- Providing a communication model between databases and the development environment;
- Analysis of the current state of the art in the field of forecasting models and, more specifically, traffic flow forecasting models;
- Learning and testing predictive models.

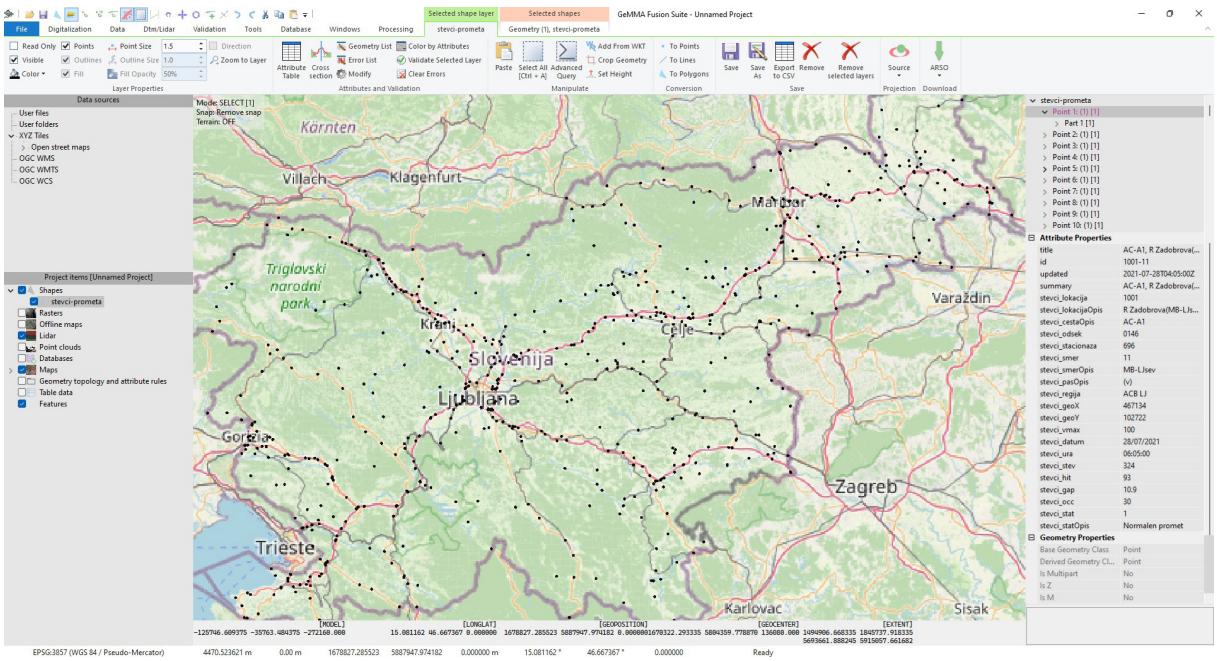



**Figure 62: Integration of data in GIS application. (Source: own)**

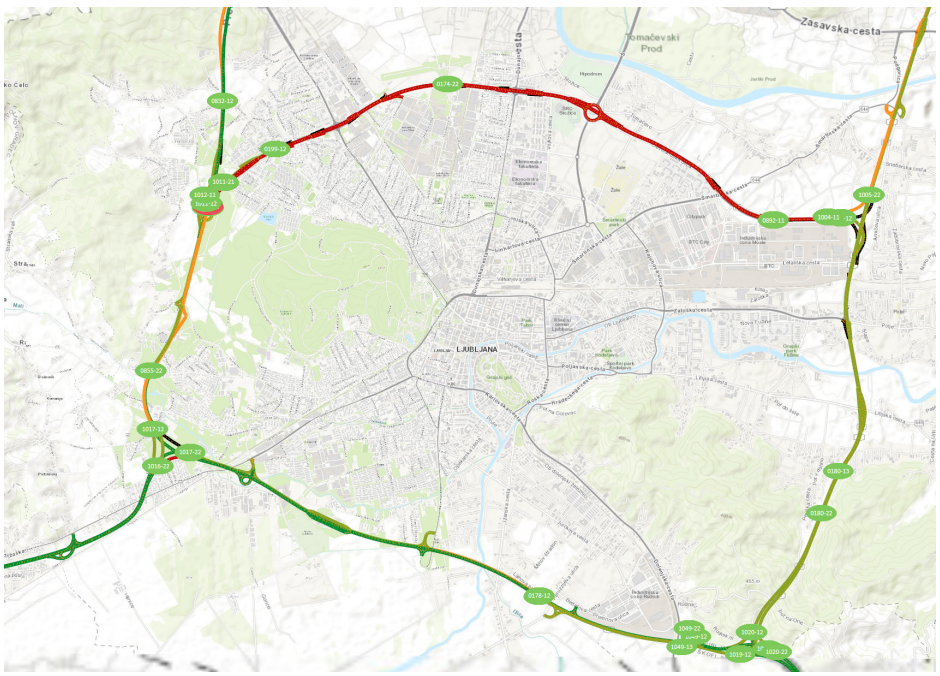



**Figure 63: Real-time predictions shown on map of Slovenia highway with a gradient ranging from green (low traffic density) to red (congestion). (Source: own)**

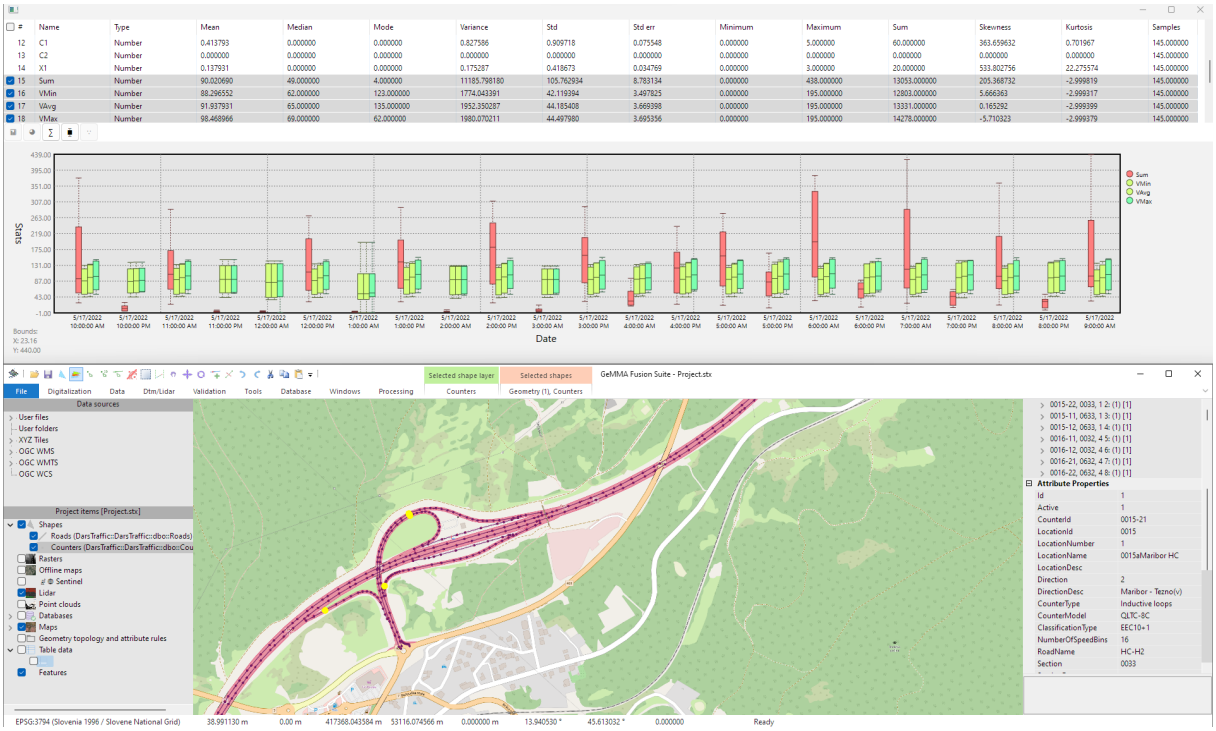



**Figure 64: Counter data statistics through the day in boxplot where red color represents the vehicle count while yellow colors show vehicle velocity distributions for multiple counters. (Source: own)**

# Development of Additional Performances of IMINT BLS – BLS ALGO

## Financed by

MORS RS

## Duration

2021 to 2022

## Partners

UM Faculty of Electrical Engineering and Computer Science, Igea d.o.o., C-Astral d.o.o., MIL Sistemika d.o.o., Onedrone d.o.o., Skylabs d.o.o., Timtec d.o.o.

The aim of the project is to develop additional software features for the Belin and Galeb drone systems. This includes the analysis of video image material obtained by UAV, including **detection and recognition of military facilities, detection of persons in the operational environment and detection of the movement of various objects in the field in near real time**.

Existing BLS capacity (Belin and Galeb) in conjunction with IMINT capacity are an integral part of ISTAR equipment and are intended for obtaining and processing intelligence from the operational environment. The existing IMINT software provides image processing mainly at the operational and strategic level, but does not contain functionalities that are important for the commander at the tactical level:

- Detection of objects or targets;
- Focusing on military facilities and targets;
- Real-time motion detection.

With the development of this function, we will increase the efficiency of image processing and, consequently, the efficiency of intelligence support.

**Figure 65: UAV monitoring the field with multiple detected objects. (Source: own)**

# Pilot System for Determining Waiting Times at Border Crossings

On the border between Slovenia and Croatia, especially during the tourist season, there are longer traffic jams. The main cause is administrative border control, which, even in the case of very fast and efficient work of the border authorities, with a large influx of vehicles, inevitably causes traffic jams. Several systems (FCD, traffic counters, bluetooth) have been tested in the past to estimate waiting times. When reviewing solutions for similar problems around the world, the technology of object recognition through video camera recordings was encountered. Therefore, the aim of this pilot project is to test such a system, which will be the basis for further planning of improving traffic information on the situation at border crossings.

**Financed by**

MZI RS

**Duration**

2022

The system supports transmition of genrated data on the actual waiting time using standard protocols via dedicated web interfaces in XML or JSON formats, which allows for the subsequent use in the various client's systems. The developed system does not collect any personal data, license plate data or other vehicle identification data.

The current waiting time before crossing the border is estimated every minute. Waiting time estimation is done by **detecting an individual vehicle and measuring the actual time that the vehicle takes over a certain distance**. Since individual vehicles are detected and tracked on the road, the developed system can detect the vehicles that do not provide relevant travel times, such as stationary vehicles or vehicles that are eliminated or excluded from traffic on the section in question. These vehicles are then filtered out before the final waiting time estimation.

The proportion of vehicles in the total traffic that the system can detect is high enough to make the data on waiting times reliable and consequently allows for error detection and correction in all weather conditions (rain, sun, night).


**Figure 66: Vehicle detection and speed monitoring in action. (Source: own)**

# An Upgrade of a Viewer for Slovenian Forest Service

## Financed by

Slovenia Forest Service d.o.o.

## Duration

2022

The forest data viewer was primarily developed to allow the employees of the Slovenia Forest Service to publish the forestry related data they collect and produce. This data is then made available to the general public through interactive GIS web application and related OGC compliant services.

The developed solution consists of several modules:

- **Backend relational database for storing vector and meta data;**
- **Backend storage for large raster data;**
- **Backend services for OGC compliant data distribution and styled map generation** (using open-source software GeoServer);
- **Backend services for GIS map caching** (using open-source software GeoWebCache);
- **Backend web application specific services** (feature identification, search queries, area data export…);
- **Interactive frontend web GIS application.**

Additionally, the forest data viewer also provides the services for computing the **land plot wood stock information** (types of trees, amount of wood and other related information). The user can download the **forest management plans** (provided by Slovenia Forest Service). Several search options allow the user to quickly locate the area of interest and then export the content as PDF or as an image.

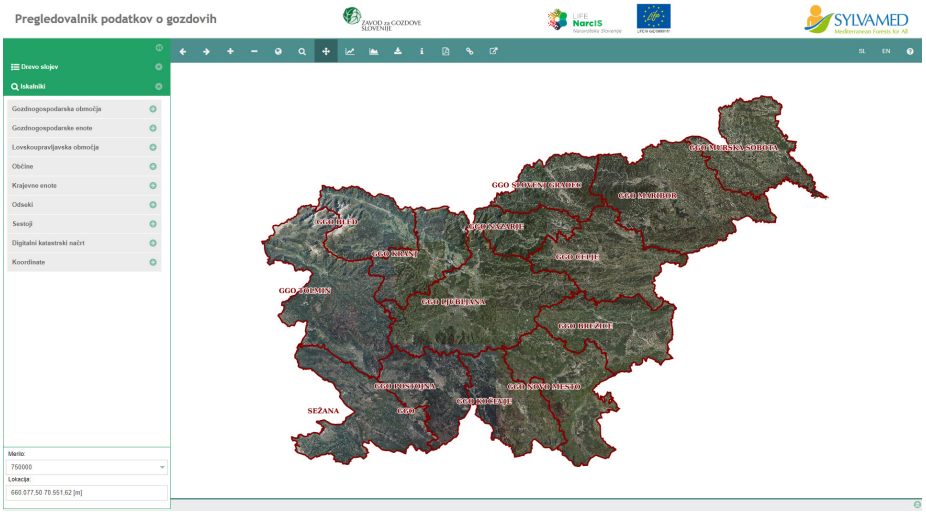



**Figure 67: Forest data viewer. (Source: own)**



ZAVOD za GOZDOVE SLOVENIJE
Slovenia Forest Service

# ACHIEVEMENTS

Prizes, Awards, Honours, Medals

Ph.D. Candidates Granted by ARRS and Completed Ph.D.s Supervised in GeMMA

Functions and Honours in National and International Associations

# Publications

## Original Scientific Articles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10. Human-Computer Interaction in Information Society. Information Society - IS 2020, Proceedings of the 23rd international multiconference, October 2020, Ljubljana, Slovenia. Vol. H. Ljubljana: Institut "Jožef Stefan", 2020. V. Pejović (editor), M. Kljun (editor), V. Groznik (editor), D. Šoberl (editor), K. Čopič Pucihar (editor), B. Blažica (editor), J. Žabkar (editor), M. Pesek (editor), J. Guna (editor), S. Kolmanič (editor).

# Prizes, Awards, Honours and Medals

## UM Awards and Honours for Employees

2022: Štefan Kohek, Recognition for exceptional contributions to scientific and pedagogical reputation and excellence of University of Maribor

2019: Niko Lukač, Recognition for exceptional contributions to scientific and pedagogical reputation and excellence of University of Maribor

2018: Domen Mongus, Award for exceptional contributions to scientific and pedagogical reputation and excellence of University of Maribor

## UM FERI Awards and Honours for Employees

2022: Dino Vlahek, Award for exceptional research achievements

2022: Matej Brumen, Plaque FERI for research and development work

2021: Blaž Repnik, Plaque FERI for research and development work

2019: Domen Mongus, Award for exceptional research achievements

2018: Damjan Strnad, Simon Kolmanič, Niko Lukač, Plaque FERI for professional work

## UM Award for Research Work of Students (Andrej Perlach's Award)

2021: Aljaž Jeromel

## UM FERI Awards for Students

Mitja Žalik, Plaque for the Best Graduate of the Second Cycle of University Study Programmes (2022)

Aljaž Žel, Award for Exceptional Student Contribution (2022 – UPM, 2022 – IEEExtreme)

Mitja Žalik,  Award for Exceptional Student Contribution (2018, 2019, 2020, 2021 – UPM, 2021 – IEEExtreme)

Mitja Žalik,  Plaque for the Best Graduate of the First Cycle of University Study Programmes (2020)

# Ph.D. Candidates Granted by ARRS and Completed Ph.D.s Supervised in GeMMA

## Ph.D. Candidates granted by Slovene Research Agency

Ph.D. candidates supervised by professor dr. Borut Žalik:

- Niko Lukač, 1 December 2012 – 31 May 2016;
- Denis Horvat, 1 October 2013 – 31 March 2017;
- David Jesenko, 1 November 2014 – 30 April 2018;
- Jernej Cukjati, 1 October 2019 – 30 September 2023.

Ph.D. candidates supervised by associate professor dr. Domen Mongus:

- Danijel Žlaus, 1 October 2016 – 22 March 2021.

Ph.D. candidates supervised by associate professor dr. Niko Lukač:

- Niko Uremović, since 1 October 2022 .

## Completed Ph.D. studies in Computer Science

All 5 disertations have been completed through UM FERI computer science & informatics study programme. Two of the disertations have been supervised by professor dr. Borut Žalik, and other three by associate professor dr. Domen Mongus, associate professor dr. Damjan Strnad, and assistant professor dr. Niko Lukač.

- Jesenko, David. Algoritem določanja funkcijske odvisnosti povezav med vozlišči v kompleksnih mrežah (An algorithm for determining the functional relation of nodes' conectivity in complex networks), 2018;
- Lukač, Niko. Algoritem za celostno vrednotenje fotovoltaičnega in vetrnega potenciala večjih geografskih območij (Algorithm for the determination of photovoltaic and wind pontential over large geographic areas), 2016;
- Žlaus, Danijel. Algoritem za učinkovit izračun verige elementarnih morfoloških filtrov na centralni procesni enoti (Algorithm for efficient computation of elementary morphological filter chain on central processing unit), 2021;

- Kohek, Štefan. Interaktivna tvorba in prikaz obsežnih področij geometrijsko raznolikih dreves (Interactive synthesis and visualization of vast areas gemoetrically diverse trees), 2019;
- Bizjak, Marko. Algoritem za napovedovanje toplotne obremenitve stavb na večjem geografskem območju (An algorithm for estimating thermal load of buildings on a large geographic area), 2019;

# Functions and Honours in National and International Associations

## dr. Borut Žalik:

- **Senior member of Association for Computing Machiner (ACM).**

  ACM brings together computing educators, researchers, and professionals to inspire dialogue, share resources, and address the field's challenges. It has nearly 100,000 members around the globe and it has led to Councils in Europe, India, and China, with its growing membership, fostering networking opportunities that strengthen ties within and across countries and technical communities.

- **Member of European Academy of Sciences and Arts (EASA) since 2014.**

  The European Academy of Sciences and Arts is a non-governmental, European association committed to promoting scientific and societal progress. Founded in 1990 as a learned society, its 2,000 members are leading scientists, artists, and practitioners of governance, who are dedicated to innovative research, interdisciplinary and transnational collaboration as well as the exchange and dissemination of knowledge. Academy members are elected for their outstanding achievements in science, arts, and governance.

## dr. Domen Mongus:

- **Member of Executive Committee of European Umbrella Organisation for Geographic Information (EUROGI) from 2013 to 2019.**

  EUROGI was established in 1994 by the European Commission with the mission is to maximise the availability, effective use and exploitation of geographic information throughout Europe in order to ensure good governance, economic and social development, environmental protection and sustainability, and informed public participation. Within the EUROGI's ExCom, Domen Mongus was serving two terms as a project portfolio leader in charge of coordinating project activities of the organisation. He was a coordinator of organisation's policy positions in regards to Big Data and Internet of Things.

- **Member of Executive Committee of Association Operating in the Field of Geographical Information Systems (GISIG) from 2019 to present.**

  GISIG is an Association operating in the field of Geographical Information Systems, grouping organisations from more than 20 European Countries. It represents a reference centre for common initiatives among Geographical Information Systems operators and users, also acting through the promotion of European projects and the establishment of thematic networks and national secretariats.

## dr. Niko Lukač:

- **Expert Evaluator for Horizon Europe Framework Programme in 2022.**

  Niko Lukač was an expert evaluator under European Commission for Innovation Action type of project calls within the Horizon Europe Framework Programme in 2022. The calls topic was related to the New Horizon Destinations for Efficient, sustainable and inclusive energy use, and Highly energy-efficient and climate neutral European building stock.

- **Member of Executive Committee of European Umbrella Organisation for Geographic Information (EUROGI) from 2019 to 2022.**

  Niko Lukač took the position as the ExCom from Domen Mongus in 2019, where we continued his work.

- **Section Editor for Data in Brief Journal from 2019 to 2022**

  Niko Lukač is a Section Editor for the field of Computer Science for the rapidly growing journal Data in brief, an open access journal by Elsevier in order to publish complementary papers for promoting and spreading scientific datasets. The journal is being managed by 2 Editors in Chief, 23 Section Editors, and 128 Editors of Editorial Board. The journal received more than 3000 submissions in 2019 alone, and almost twice the number of submissions are expected in 2020.

# GeMMA Activity Report 2016–2022

Tamara Golob

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**Abstract:** The primary aim of this publication is to support the dissemination of the research achievements of GeMMA Laboratory at the Faculty of Electrical Engineering and Computer Science of the University of Maribor. It follows the first survey published in 2016, and therefore, the actual book concentrates on the research results since then. The previous book, covering a period of 17 years, presented 35 R&D projects, while the new review of activities over the last 7 years covers as many as 58 projects. This growth is a good cue to introduce the secondary, equally important aim of the book. Namely, we would like to leave the track to our successors to stimulate them for even better research results, to show them, what is possible to achieve in 22 years starting from scratch with the will, hard work, orientation towards the applications, devotion to the research work, and the strong team spirit.

**Keywords:** research & development projects, geospatial modelling, multimedia, artificial intellingence, algorithms, industrial cooperation, international cooperation

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