Lecture Notes in Computer Science **16769**

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Computational Science and Its Applications – ICCSA 2026

26th International Conference
Braga, Portugal, June 30 – July 3, 2026
Proceedings, Part III

Springer

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ISSN 0302-9743 ISSN 1611-3349 (electronic)
Lecture Notes in Computer Science
ISBN 978-3-032-30493-3 ISBN 978-3-032-30494-0 (eBook)
https://doi.org/10.1007/978-3-032-30494-0

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Preface

These 3 volumes (LNCS volumes 16767–16769) comprise the peer-reviewed papers from the 6 tracks of the 2026 International Conference on Computational Science and Its Applications (ICCSA 2026), held between June 30 and July 3, 2026, in Braga (Portugal). The peer-reviewed papers from the 57 Workshops are published in a separate set of 9 volumes (LNCS 16758–16766).

The conference was held in a hybrid format, with the vast majority of participants attending in person, hosted by the University of Minho in Braga, Portugal. We enabled virtual participation for those who did not attend the event in person due to logistical, political, or economic constraints by adopting a technological infrastructure based on open-source software (Jitsi + Riot) and a commercial Cloud infrastructure. ICCSA 2026 was organized by the University of Minho (Portugal), the University of Perugia (Italy), the University of Basilicata (Italy), the University of Cagliari (Italy), Monash University (Australia), and Kyushu Sangyo University (Japan).

With the 2026 edition, ICCSA celebrated its 26th anniversary, marking a new chapter in its longstanding history after its memorable 25th anniversary celebrated in Istanbul, Türkiye. Hosted in Braga, Portugal, the conference found a particularly meaningful setting in one of Europe's oldest and most vibrant academic cities, a place where historical depth, cultural continuity, and contemporary scientific exchange meet. Braga offers an inspiring European context for renewing the international and intercultural dialogue that has always characterized ICCSA, while giving new visibility to the role of computational science in addressing the complex challenges of cities, territories, technologies, and societies.

ICCSA 2026 marked another fruitful and thought-provoking academic event in the International Conferences on Computational Science and Its Applications (ICCSA) conference series, previously held in Istanbul, Türkiye (2025), Hanoi, Vietnam (2024), Athens, Greece (2023), Málaga, Spain (2022), Cagliari, Italy (hybrid with few participants in presence in 2021 and completely online in 2020), whilst earlier editions took place in Saint Petersburg, Russia (2019), Melbourne, Australia (2018), Trieste, Italy (2017), Beijing, China (2016), Banff, Canada (2015), Guimarães, Portugal (2014), Ho Chi Minh City, Vietnam (2013), Salvador, Brazil (2012), Santander, Spain (2011), Fukuoka, Japan (2010), Suwon, South Korea (2009), Perugia, Italy (2008), Kuala Lumpur, Malaysia (2007), Glasgow, UK (2006), Singapore (2005), Assisi, Italy (2004), Montreal, Canada (2003), and (as ICCS) Amsterdam, the Netherlands (2002) and San Francisco, USA (2001).

Computational Science constitutes the main pillar of most present research, industrial and commercial applications, and plays a unique role in exploiting innovative ICT technologies, and the ICCSA conference series has, accordingly, provided ample opportunities to researchers and industry practitioners to discuss new ideas, to share complex problems and their solutions, and to shape new trends in Computational Science. As the conference mirrors society from a scientific point of view, this year's undoubtedly

dominant theme was large language models, machine learning, and Artificial Intelligence (AI), and their applications across the most diverse technological, economic, and industrial fields, amongst others.

The ICCSA 2026 conference was structured into six general tracks covering computational science and its applications: Computational Methods, Algorithms and Scientific Applications; High-Performance Computing and Networks; Geometric Modelling, Graphics and Visualisation; Advanced and Emerging Applications; Information Systems and Technologies; and Urban and Regional Planning. In addition, the conference included 57 workshops, focusing on topical issues of utmost importance to science, technology, and society: from new computational approaches for earth science, to mathematical methods for image processing, new statistical and optimisation methods, several Artificial Intelligence approaches, sustainability issues, smart cities and related technologies, to name some.

In the Main Conference Proceedings, we accepted 119 full papers, 3 short papers and 2 Ph.D. Showcase papers on 405 submissions to the General Tracks of the Conference (with an acceptance rate of 29.9%). Reviews were single blind, and submissions received 2.6 reviews each, on average. In the Workshops proceedings, we accepted 321 full papers, 23 short papers and 3 Ph.D. Showcase papers from a total of 1184 submissions (Acceptance rate 29.9%). We would like to convey our sincere appreciation to the workshop chairs and co-chairs, and program committee members, for their diligent work, commitment, and dedication.

The success and consistent maintenance of the ICCSA conference series in general, and of ICCSA 2026 in particular, rely upon the support of many people: authors, presenters, participants, keynote speakers, workshop chairs, session chairs, Organizing Committee members, student volunteers, Program Committee members, Advisory Committee members, International Liaison chairs, reviewers, and other individuals in various roles. Thus, we take this opportunity to wholeheartedly thank each and every one.

We also wish to thank the publisher, Springer, for accepting the proceedings, for sponsoring part of the best paper awards, and for their kind assistance and cooperation during the editing process. We would cordially like to invite you to refer to the ICCSA website https://iccsa.org, where you can find the relevant details regarding this academic endeavour and our event.

June 2026

Chiara Garau
Ana Maria A. C. Rocha
Osvaldo Gervasi
Beniamino Murgante

Welcome Message from the Organizers

On behalf of the Local Organizing Committee of ICCSA 2026, it is our great pleasure to welcome you to the 26th International Conference on Computational Science and Its Applications, held from June 30 to July 3, 2026, at the University of Minho in Braga, Portugal.

We are deeply honoured by the trust placed in us by the ICCSA General Chairs in organizing another edition of this successful conference series. We hope that ICCSA 2026 provided an inspiring environment for scientific exchange, collaboration, and discussion among researchers from all over the world.

The conference took place at the University of Minho, one of the most prestigious higher education institutions in Portugal. Founded in 1973, the University of Minho has campuses in Braga and Guimarães and is widely recognized for its academic excellence, research activity, and strong international outlook.

Braga, one of the oldest cities in Portugal, is renowned for its historical heritage, cultural vitality, and welcoming atmosphere. Located in the heart of the Minho region, the city combines tradition with modernity, offering visitors renowned gastronomy, beautiful landscapes, and the unique character of *Vinho Verde* wine.

The scientific program of ICCSA 2026 included plenary lectures delivered by distinguished scientists, together with a broad range of workshops covering several areas of Computational Science and its Applications. We believe that the conference provided excellent opportunities to share ideas, discuss emerging challenges, and foster new collaborations.

In addition to the scientific sessions, participants had the opportunity to enjoy a rich social program. Planned activities included a Welcome Reception at Largo do Paço, the Rectorate of the University of Minho, located in the former Archbishop's Palace - one of the most emblematic historical buildings in the city center; a *Vinho Verde* wine tasting experience at Quinta d'Amares, where you can discover the art of winemaking; and a guided visit to the coastal city of Viana do Castelo, renowned for its maritime heritage, traditional architecture, and beautiful Atlantic scenery. The conference gala dinner took place at Colunata Eventos, located within the Bom Jesus do Monte sanctuary, a UNESCO World Heritage Site, where ICCSA participants enjoyed delicious recipes and a wonderful view over the city of Braga.

The success of ICCSA 2026 would not have been possible without the dedication and enthusiasm of many collaborators and volunteers, whose hard work and commitment greatly contributed to the organization of the conference. On behalf of the Local Organizing Committee, it was our honour to warmly welcome you to the beautiful city of Braga and we hope you had an enjoyable and productive conference.

Sincerely yours,

On behalf of the Local Organizing Committee

Ana Maria A. C. Rocha

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General Tracks

1. Computational Methods, Algorithms and Scientific Applications

Computational Biology
Computational Combustion
Computational Chemistry
Computational Fluid Dynamics
Computational Physics
Computational Geometry
Computational Mathematics
Computational Mechanics
Computational Electro-magnetics
Numerical Methods and Algorithms

2. Track: High Performance Computing and Networks

Parallel and Distributed Computing
Cluster Computing
Supercomputing
Cloud Computing
Autonomic Computing
P2P Computing
Mobile Computing
Edge Computing
Workflow Design and Practice
Computer and Network Architecture

3. Track: Geometric Modeling, Graphics and Visualization

Scientific Visualization
Computer Graphics
Geometric Modeling
Pattern Recognition
Image Processing
CAD/CAM
Web3D, Virtual and Augmented Reality

4. Track: Advanced and Emerging Applications

Biochemistry
Bioinformatics
Astrophysics

Biometric Modeling
Environmental, Climate and Weather Modeling
Geology and Geophysics
Nuclear Physics
Financial and Economical Modeling
Computational Journalism

5. Track: Information Systems and Technologies

Information Retrieval
Scientific Databases
Security Engineering
Risk Analysis
Reliability Engineering
Software Engineering
Data Mining
Artificial Intelligence
Machine Learning
Learning Technologies
Web Based Computing
Web 2.0
Blockchain

6. Track: Urban and Regional Planning

Urban and regional growth
Sustainable urban and regional development
Socio-ecological systems
Open Data- Big Data
Cultural Heritage
Smart and Sustainable Cities
Mobility and Intelligent Transport Systems
Geographical Information Systems
Decision Support Systems
Complexity assessment and mapping
Logistics

Workshops

Workshop on Advancements in Applied Machine-Learning and Data Analytics (AAMDA 2026)

Workshop Organizers:

Alessandro Costantini	INFN, Italy
Elisabetta Ronchieri	INFN CNAF, Italy

Artificial Intelligence Tools In Managing Future Communities (AiMFutCOM 2026)

Workshop Organizers:

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Francesco Scorza	University of Basilicata, Italy
Donatello Cardone	University of Basilicata, Italy
Maurizio Pollino	ENEA, Italy
Gregorio DAgostino	ENEA, Italy

Advanced and Innovative Web Apps 2026 (AIWA 2026)

Workshop Organizers:

Damiano Perri	University of Perugia, Italy
Osvaldo Gervasi	University of Perugia, Italy
Luciano Alessandro Ipsaro Palesi	University of Florence, Italy

Advanced Mathematics and Computing Models in Complex Data-Intensive Computational Systems (AMCM 2026)

Workshop Organizers:

Yeliz Karaca	UMass Chan Medical School and Massachusetts Institute of Technology, USA
Dumitru Baleanu	Lebanese American University, Lebanon
Osvaldo Gervasi	University of Perugia, Italy
Yudong Zhang	University of Leicester, UK
Majaz Moonis	UMass Chan Medical School, USA

Advanced Numerical Approaches for Assessment and Design of No-Tension Masonry Structures (ANAMS 2026)

Workshop Organizers:

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Natalia Pingaro	Politecnico di Milano, Italy
Andrea Montanino	International Centre for Numerical Methods in Engineering, Spain
Elham Mousavian	University of Edinburgh, UK
Stefano Galassi	University of Florence, Italy

Artificialization of land, Urban Transformation, and Territorial Resilience in a Changing Climate (AUTTREC 2026)

Workshop Organizers:

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Hassan Radoine	Mohammed VI Polytechnic University, Morocco
Cezar Morar	University of Oradea, Romania
Antonio García Martínez	Universidad de Sevilla, Spain
Clara Stella Vicari Aversa	Università degli Studi Mediterranea di Reggio Calabria, Italy

Blockchain and Distributed Ledgers: Technologies and Applications (BDLTA 2026)

Workshop Organizers:

Vladimir Korkhov	Saint Petersburg State University, Russia
Elena Stankova	Saint Petersburg State University, Russia
Nataliia Kulabukhova	AutoTech, Russia

Bio and Neuro inspired Computing and Applications (BIONCA 2026)

Workshop Organizers:

Nadia Nedjah	State University of Rio de Janeiro, Brazil
Luiza de Macedo Mourelle	State University de Rio de Janeiro, Brazil

Computational and Applied Mathematics (CAM 2026)

Workshop Organizers:

Maria Irene Falcao	University of Minho, Portugal
Fernando Miranda	Universidade do Minho, Portugal

Computational and Applied Statistics for Data and AI (CAS 2026)

Workshop Organizers:

Ana Cristina Braga	University of Minho, Portugal
Ines Sena	University of Minho, Portugal
Joao Mendes	Polytechnic Institute of Bragança, Portugal

Circular Economy and Territorial Competitiveness (CETC 2026)

Workshop Organizers:

Gerardo Carpentieri	University of Naples Federico II, Italy
Carmen Guida	Università degli Studi di Napoli Federico II, Italy
Floriana Zucaro	University of Naples Federico II, Italy
Zhadyra Konurbaeva	D. Serikbayev East Kazakhstan Technical University, Kazakhstan
Saule Kumargazhanova	D.Serikbayev East Kazakhstan Technical University, Kazakhstan

Circular Ecological Heritage Communities: Regeneration and Evaluation Strategies for Historic Villages, Landscapes and Rural Territories (CHEC 2026)

Workshop Organizers:

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Antonia Gravagnuolo	CNR Institute of Heritage Science, Italy
Francesca Buglione	CNR ISPC, Italy
Piera Della Morte	Pegaso Telematic University, Italy

Cyber Intelligence and Applications (CIA 2026)

Workshop Organizers:

Gianni DAngelo	University of Salerno, Italy
Francesco Palmieri	University of Salerno, Italy
Massimo Ficco	University of Salerno, Italy

Computational Methods, Statistics and Industrial Mathematics (CMSIM 2026)

Workshop Organizers:

Maria Filomena Teodoro	CINAV, Escola Naval, Instituto Universitário Militar, Portugal
Paula Simões	Academia Militar, Portugal
Teresa A. Oliveira	University of Lisbon and Universidade Aberta, Portugal

Computational Optimization and Applications (COA 2026)

Workshop Organizers:

Ana Maria A. C. Rocha	University of Minho, Portugal
Humberto Rocha	University of Coimbra, Portugal

Computational Methods in Advanced Networking Technologies (CoMANT 2026)

Workshop Organizers:

Eslam Farsimadan	University of Salerno, Italy
Leila Moradi	University of Salerno, Italy
Francesco Palmieri	University of Salerno, Italy

Computational Astrochemistry 2026 (CompAstro 2026)

Workshop Organizers:

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Computational Methods for Porous Materials (CompPor 2026)

Workshop Organizers:

Vadim Lisitsa	Institute of Petroleum Geology and Geophysics SB RAS, Russia
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Workshop on Computational Science and HPC (CSHPC 2026)

Workshop Organizers:

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Robert Makin	Western Michigan University, USA

Cities, Technologies and Planning (CTP 2026)

Workshop Organizers:

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Evaluating Inner Areas Potentials (EIAP 2026)

Workshop Organizers:

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sustainablE mobiLity and Last mIle lOgisTic in Urban Context (ELLIOT 2026)

Workshop Organizers:

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Ecosystem Services in Spacial Planning for Climate Neutral Urban and Rural Areas (ESSP 2026)

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The 16th International Workshop on Future Information System Technologies and Applications (FiSTA 2026)

Workshop Organizers:

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Geographical Analysis, Urban Modeling, Spatial Statistics (Geog-And-Mod 2026)

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Andreas Fricke	Hasso Plattner Institute for Digital Engineering, University of Potsdam, Germany

Generative and Neuro-Symbolic Artificial Intelligence for Real-World Systems (GNS-AI 2026)

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Geomatics for Resource Monitoring and Management (GRMM 2026)

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Multidimensional Evolutionary Evaluations for Transformative Approaches (MEETA 2026)

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Building Multi-dimensional Models for Assessing Complex Environmental Systems (MES 2026)

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Computational Mechanics, Intelligence, and Data (MIND 2026)

Workshop Organizers:

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Modelling Liveable Cities: Techniques, Methods, Challenges, and Perspectives Behind the X-Minute City (MLC 2026)

Workshop Organizers:

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Mathematical Methods for Image Processing and Understanding 2026 (MMIPU 2026)

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MOdels and Indicators for Assessing and Measuring the Urban Settlement deVElopment in the View of NET ZERO by 2050 (MOVEto0 2026)

Workshop Organizers:

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Numerical Aspects in Machine Learning for Dynamical Systems (NAMLYS 2026)

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Scientific Computing Infrastructure (SCI 2026)

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Socio-Economic and Environmental Models for Land Use Management (SEMLUM 2026)

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Ports and Logistics of the Future - Smartness and Sustainability (SmartPorts 2026)

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Sustainable Evolution of Long-Distance frEight and paSsenger Transport (SOLIDEST 2026)

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Sustainability Performance Assessment: Models, Approaches, and Applications Toward Interdisciplinary and Integrated Solutions. (SPA 2026)

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Specifics of Smart Cities Development in Europe (SPEED 2026)

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Smart, Safe, and Health Cities (SSHC 2026)

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Workshop Organizers:

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Sustainable Tourism Economy, Silk Road, Reuse and Enhancement of Cultural Heritage (STESilkRoad 2026)

Workshop Organizers:

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Transport Infrastructures for Smart Cities (TISC 2026)

Workshop Organizers:

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Transforming Urban Analytics: The Impact of Crowdsourced Mapping and Advanced AI Techniques on Future Cities (Tr-UrbAna 2026)

Workshop Organizers:

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From Structural to TRAnsformative-Change of City Environment: Challenges and Solutions and Perspectives (TRACE 2026)

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Urban Artificial Intelligence for Modelling, Analysis and Planning (Urban plAnnIng 2026)

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Urban Space Accessibility and Mobilities (USAM 2026)

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Virtual Reality, Augmented Reality and Applications (VRA 2026)

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Workshop on Advanced and Computational Methods for Earth Science Applications (WACM4ES 2026)

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ICCSA 2026 would not have been possible without the tremendous support of many organizations and institutions, for which all organizers and participants of ICCSA 2026 express their sincere gratitude:



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Venue

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Plenary Lectures

Digital Twins for Cities – The Rise of the Socio-Technical System

Claudia van der Laag

Professor of Urban Analytics, Department of Built Environment, Oslo Metropolitan University, Oslo

Abstract. Cities are entering a new era in which digital twins are no longer simply technical replicas of urban systems, but evolving socio-technical infrastructures that shape how cities are planned, governed, and experienced. Across the world, urban digital twins are being adopted to address some of the most pressing challenges of our time—climate adaptation, urban resilience, mobility transitions, decarbonisation, infrastructure management, and inclusive governance. Yet as these technologies become increasingly sophisticated, a fundamental question emerges: can digital twins truly support more democratic and human-centred cities, or will they reinforce existing structures of power and expertise? In this keynote, Claudia van der Laag, explores the transformation of urban digital twins from data-driven modelling tools into collaborative platforms for urban decision-making and societal change. It argues that the future of digital twins lies not only in advances in artificial intelligence, real-time data integration, simulation, and predictive analytics, but equally in the ability to connect technological innovation with governance, participation, and human agency. Drawing on emerging international research and practical case studies, the keynote examines the complex ecosystem surrounding urban digital twins, bringing together planners, policy-makers, researchers, technologists, and communities. It highlights how digital twins increasingly function as meeting points between multiple forms of knowledge—technical, political, social, and experiential—and why interdisciplinary collaboration is essential for their success. The talk will critically reflect on the tensions between technological ambition and civic inclusion, exploring themes such as transparency, interoperability, participation, and trust. It will also discuss how digital twins can become powerful environments for scenario exploration, urban experimentation, and collective learning, enabling cities to better navigate uncertainty and complexity in an age of rapid urban transformation. Ultimately, this keynote presents a vision of digital twins not as neutral technological systems, but as living socio-technical infrastructures capable of reshaping urban governance itself. The challenge ahead is therefore not only how accurately cities can be modelled, but how inclusively they can be imagined, negotiated, and governed through these emerging digital environments.

Short Bio – Claudia van der Laag (also known as Claudia Yamu) is Professor of Urban Analytics at Oslo Metropolitan University. Her work advances urban analytics and spatial modelling through an integrated multi-method approach, informing sustainable urban planning and policy. She is widely recognised for bridging theory and practice and received the prestigious Michael Breheny Prize for her contributions to multi-scale

modelling. Van der Laag is co-author of the widely recognised textbook ‘Introduction to Space Syntax in Urban Studies’. She also serves on the editorial advisory board of Springer’s The Urban Book Series and the journal Environment and Planning B: Urban Analytics and City Science.

Prescriptive AI in Practice: Bridging Optimisation, Generative AI and Agentic Decision-Making

Bernardo Almada-Lobo

Universidade do Porto, Faculdade de Engenharia, INESC TEC, Portugal

Abstract. Prescriptive AI, viewed through the lens of mathematical optimisation and operations research, addresses complex business decision-making problems involving limited resources, multiple decision options and competing objectives. This talk considers the full decision pipeline: problem framing, model formulation, computational solution, implementation, monitoring and organisational adoption. The practical success of prescriptive AI depends less on algorithmic sophistication alone than on the quality of the translation between real-world decision contexts and formal optimisation models. In practice, this translation remains a major bottleneck. Objectives are often ambiguous, constraints are incomplete or tacit, data may be fragmented, and the operational consequences of a recommendation may be poorly understood. As a result, optimisation projects can fail even when the underlying mathematical model is technically sound. The talk will address the persistent gap between optimisation theory and deployment practice. While optimisation has generated substantial value in domains such as supply chain planning, logistics, production, revenue management, workforce planning and inventory control, many initiatives still face a significant risk of under-delivery. Common failure modes include incorrect problem framing, weak data readiness, brittle assumptions, infeasible or non-actionable recommendations, limited explainability, insufficient ownership by business users and inadequate post-deployment monitoring. Crossing this gap requires moving from one-off model building to an operational lifecycle in which models are stress-tested, embedded in workflows, monitored for drift and revised as the business environment changes. Recent developments in generative and agentic AI create new opportunities to reduce these barriers. Generative AI can support the elicitation of decision-maker preferences, the structuring of unstructured operational knowledge, the drafting of candidate formulations and the explanation of model outputs in business language. Agentic AI can extend this role by orchestrating multi-step workflows that involve model formulation, solver-code generation, execution, debugging, infeasibility diagnosis, sensitivity analysis and human review. However, these capabilities should not be interpreted as replacing optimisation expertise. Rather, they create a new interface between human judgement, analytical modelling and computational decision support. This talk will discuss a cross-fertilisation agenda between optimisation, generative AI and agentic AI, with a focus on how these technologies should be calibrated to the decision at hand.

Short Bio – Full Professor of Industrial Engineering and Management at the Faculty of Engineering of University of Porto (FEUP). Co-founder and Partner at LTPlabs, a Business AI company. Member of the Board of Trustees of the Belmiro de Azevedo

Foundation. Member of the Academy of Engineering. Former Board Member of INESC TEC and Researcher at the MIT Sloan School of Management. Holds a BEng, PhD and Habilitation in Industrial Engineering and Management from FEUP. Completed the Advanced Management Programme at INSEAD, and the Mergers and Acquisitions at London Business School. Certified Analytics Professional (CAP) by INFORMS. His area of activity is Business Analytics and Artificial Intelligence. He researches, develops and implements analytical models and methods to support decision-making, solving management problems across various domains—manufacturing, consumer goods, retail and transport—with a particular focus on Operations Management and the Operations–Marketing interface. He has coordinated and participated in more than 300 development, consultancy and research projects funded by private organisations, science agencies from several countries, the European Commission and regional bodies. He has published more than 100 scientific articles and is co-author of the book Analytics Sandwich: Bringing People and Artificial Intelligence Together to Unlock Business Value. He has supervised more than 20 doctoral theses.

Net-Zero Communities Through Life Cycle Thinking: Canadian Lessons and Global Implications

Kasun Hewage

Professor of Engineering, School of Engineering (Okanagan Campus), The University of British Columbia (UBC), Canada, FortisBC Smart Energy Chair, Associate Director, Clean Energy Research Centre (CERC)

Abstract. This keynote presentation discusses how life cycle thinking supports the transformation of communities toward sustainable, resilient, and net-zero futures. Drawing on Canadian research, practice, and policy experience, the presentation highlights how integrated life cycle approaches can move beyond conventional carbon accounting to inform practical decision-making across buildings, infrastructure, energy systems, waste management, water systems, and industrial processes [1-8]. The keynote features research conducted at the Life Cycle Management Laboratory (LCML) at the University of British Columbia, Canada, an internationally recognized research hub led by Prof. Kasun Hewage. LCML brings together engineers, scientists, policy researchers, postdoctoral fellows, visiting scholars, and graduate researchers to translate data-intensive sustainability research into actionable climate solutions. The laboratory's work is organized around six interconnected research themes: energy systems, urban development, water systems, waste management, construction and asset management, and industrial processes and products. Together, these themes provide an integrated platform for advancing life cycle–based pathways to net-zero communities. Supported by strong partnerships with government, industry, and community stakeholders, LCML has contributed to a substantial body of applied sustainability research, including more than 400 journal articles, 100 conference papers, and numerous technical reports that have informed real-world planning and implementation. This keynote presentation highlights selected success stories that demonstrate how life cycle thinking can be translated into practical strategies for reducing environmental impacts while strengthening community resilience. These insights are especially relevant to the interdisciplinary focus of ICCSA 2026, which will be held in collaboration with the University of Minho in Braga, Portugal, from June 30 to July 3, 2026.

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Short Bio – Prof. Kasun Hewage is a Full Professor and FortisBC Smart Energy Chair in the School of Engineering at the University of British Columbia. He also serves as Associate Director of UBC's Clean Energy Research Centre and Director of the Life Cycle Management Laboratory. Prof. Hewage brings extensive multidisciplinary industrial experience in Canada and internationally. Prior to joining UBC in 2008, he worked as a business management cost specialist in the oil and gas sector and as a civil engineer on hydropower and infrastructure development projects. His research focuses on integrating life-cycle thinking into urban development, energy policy, and infrastructure planning. A distinctive feature of his work is its whole-system perspective, extending beyond conventional assessment methods to evaluate products, processes, and built assets from material extraction through end-of-life. Through this approach, Prof. Hewage and his research team have supported governments, infrastructure developers, and communities in advancing low-impact and net-zero development strategies for both existing and planned communities. Prof. Hewage currently leads many collaborative research projects on life-cycle management of built assets, green construction, smart energy systems, and sustainable community planning. His contributions have helped establish important benchmarks, decision-support methods, and implementation pathways for advancing sustainability in the Canadian and global construction sectors. He has authored or co-authored more than 300 peer-reviewed journal publications, in addition to numerous book chapters and conference papers presented at national and international forums. Prof. Hewage is registered as a Professional Engineer in British Columbia, Canada. He is a Fellow of the Canadian Society for Civil Engineering, the Canadian Society of Senior Engineers, and the Engineering Institute of Canada.

Machine Learning Based Methodologies for Grape and Wine Production

Pedro Melo-Pinto

University of Trás-os-Montes and Alto Douro, Engineering Department, Centre for the Research and Technology of Agro-Environmental and Biological Sciences, Portugal

Abstract. Wine production is a major area in Portuguese economy. The sector accounts for approximately 2.6% of Portugal's GDP, and is crucial to the development of inland regions. Wine quality depends on grape quality, which is a result of different factors such as harvesting at the optimal point of maturity, or selecting the grapes according to quality features. The growing importance of precision agriculture, demands novel methods to make the most out of the data generated. Machine learning approaches are particularly suitable for complex processes' modelling, where too many arguments are involved. Many of the agricultural processes such as yield estimation or ripening, fall into this category. However, several challenges may arise: even if models are available for particular cases, general models are difficult to come by, largely due to the high variability involved; with such models, there is a need for huge amounts of data, in a way which will not always be easy to obtain. This is particularly true in the case of grape production and the wine industry, where the number of grape varieties, climate, soil, etc., introduce a degree of variability that is uncommon in other sectors. One way of obtaining more information in such cases has been the use of images, whether RGB, multi-spectral or hyperspectral. The use of images introduces additional challenges, such as data size and lighting conditions, which underscores the need for data-driven modelling methodologies. The use of machine learning (ML) techniques combined with images has been establishing itself as a viable alternative predicting yields or quality parameters in grapes, and assist on harvesting critical decisions. Several ML approaches have been proposed to handle such data characteristics, but selecting a suitable methodology that best address the problem under study and make sure it generalizes well, is, most of the times, a cumbersome task. We will address three wine and grape production problems, yield estimation, grape quality assessment and illness detection, presenting different difficulties. Yield estimation is a major aspect in the wine production industry. The number of berries is one of the most relevant yield aspects, and can be estimated using computer vision, namely image segmentation algorithms. Lighting is one of the key factors in computer vision approaches, and occlusions—which are common in this problem—can be minimized, but require estimation models to achieve reliable results. Illness early detection is, of course, of the utmost importance, with an impact on production and quality. Detecting early symptoms and distinguishing them from other conditions is a difficult task, which makes the use of machine learning algorithms advisable, using automatic visual inspection of the leaves, addressed as a pixel-based classification problem. However, the available datasets are limited and complex to compile, as different diseases typically require very

specific timeframes and locations. The use of generative models to overcome this obstacle, in conjunction with robust classification models, lead to models that are intended to be as general as possible. The evaluation of the grape's maturation profile based on the evolution of their oenological parameters over time is one of the most important aspects for ensuring wine quality, playing a decisive role in the definition of the optimal time for harvesting. The use hyperspectral imaging combined with learning algorithms represents a faster and non-destructive grape ripeness assessment method. We focus in two fundamental aspects to address the resulting data variability: a possible wavelength bands selection (with the purpose of reducing the dimensionality of data without losing predictive power) and the generalization ability of the ML model under such demanding conditions.

Short Bio – Pedro Melo-Pinto graduated from Univ. do Porto in 1984 and received a Ph.D. in Computer Science from the Univ. de Trás-os-Montes e Alto Douro (UTAD) in 1998. He is a Full Professor at UTAD where he served as Pro-Rector, as Director and Vice-Director of R&D units, and as member of UTAD's General Council. He also served as a member of The Portuguese Strategic Infrastructures (for the Digital Areas) Monitoring Committee and usually serves as a member (or co-chair) of the evaluation panel for different Portuguese and international R&D projects and grants competitions. He is currently Associate Editor of Computers and Electronics in Agriculture journal. He was Chair of the EuroFuse 2011 conference and the NATO 2001 Advanced Research Workshop, and served as member of the organization committee for more than 40 international conferences/workshops/special sessions. He is the head of the Image-Based Systems Lab from the Centre for the Research and Technology of Agro-Environmental and Biological Sciences.

His scientific interests include Computer Vision (CV) and Machine Learning (ML) and, in the last 15 years, their applications to the Agro-forestry area, namely to grape oenological parameters assessment. He authored/co-authored more than 100 scientific papers. He participated in many Portuguese and international R&D projects, predominantly in the areas mentioned above.

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