Technology Platform for Hydroinformatics Systems

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Abstract. This paper sheds light on the authors' extensive involvement in the development and use of hydroinformatics systems in Serbia and the surrounding region. The definition of the hydroinformatics system, a list of its potential applications, and a summary of current best practices worldwide are all provided in the introduction. An overview of the general platform that was developed using knowledge gained during the creation of various systems is also presented. We have discussed the features built into a single software platform that uses computational services and mathematical models. With the specifics of implementation in line with the goal and traits of the researched systems, a variety of real-world examples of application by the Institute are presented.

Keywords: hydroinformatics · hydro-information system · software platform · hydrological modelling · hydraulic modelling · decision-support tool

1 Introduction

To address the serious issues of equitable and effective water use for various purposes, hydroinformatics, an interdisciplinary field of technology has emerged from computational hydraulics [1]. Hydroinformatics focuses on the integration of information and communication technologies with hydrology, hydraulics, environmental science, and engineering. Many cutting-edge uses of contemporary information technology are included in hydroinformatics for the management and decision-making of water resources. The most recent IT advancements in artificial intelligence (including knowledge-based systems, machine learning, evolutionary algorithms, and artificial neural networks), artificial life, cellular and finite state automata, as well as other, previously unrelated sciences and technologies, are also utilized.

In its widest meaning, hydroinformatics refers to the use of information technology in the water industry. One of them is hydroinformatics systems (HIS), which have emerged as a way to aid in the optimal management of water resources as well as to resolve current and future disputes within a specific basin or in a particular region in relation to conflicts of interest or development projects that exist in different states, local communities, individual companies, and other legal or physical bodies. In contrast

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to hydroinformatics systems, which are broader systems that include electricity generation, water supply, irrigation, flood and drought risk assessment, water quality and other artificial activities within the system, hydrological information systems are only a component that are common to most HIS systems and are typically characterized by a single-purpose application.

The creation and implementation of the hydroinformatics system requires the creation of a sophisticated software platform with an emphasis on the user (user applications), real-time system execution (services), and specialized system administration (administrator tools). This system includes software components for quick and safe data access by users through specialized applications designed to support system management. It also offers comprehensive and precise data retrieval methods from multiple sources, their validation, processing, and archiving. This group of HIS data management components enables the creation of software for “real-time” formation of an up-to-date computational state of the system, bringing HIS as an IT platform for management support closer to daily operational use with the least amount of human resources required.

2 Hydroinformatics Systems in Practice

Modern hydroinformatics systems are evolving in a way that suggests more flexibility in applying various models. The Open Modelling Interface (OpenMI), which focuses on integrating models and tools in the environmental domain with an emphasis on water, was introduced at the end of 2005. Due to the accessibility of computer resources and the widespread use of deep learning (DL) algorithms in numerous water resource data analyses and hydrological activities, DL research has experienced substantial growth.

Deep learning models [2], together with increased data [3], image synthesis [4], and web-based modeling [5], have been employed more and more in hydrological research in recent years. In the form of serious games, simulation techniques that take participant input into account are also suitable for the management of water resources [6]. The present trend toward “digitalization” of water [7] is particularly significant since it should provide the most comprehensive picture of the health of water resources in real time by fusing data and models with risk management.

Because of large amount of data accessible in contemporary information systems in the subject of hydroinformatics, processing them with standard techniques may be challenging. As a result, it is crucial to take into account the use of Big data approaches in hydroinformatics [8].

The functions for data and model management, data assimilation in hydrological and hydraulic models, as well as a description of the functionality of decision support tools, are some of the ways in which this paper contributes to the knowledge and idea of HIS.

3 Hydroinformatics System Technology Platform

The development and deployment of HIS for a particular system entails the implementation of the fundamental set of features. Since data management is the fundamental function of every HIS, specific software components relating to data gathering, archiving, and processing must be included. In addition, regardless of HIS’s intended use, the functionality of organizing mathematical models and calculations is implied. Individual implementations can only be separated in terms of the management support capabilities that depends on the HIS's intended use, as not all HISs are designed to support decision-making at both the operational and strategic management levels. The authors, who are Jaroslav Černi Institute experts, determined the general structure of HIS based on their experience in the construction of numerous HISs, as indicated in the following figure (Fig. 1).

The background-running software components are logically divided into three categories: acquisition, central, and compute server. User tools are divided into four categories based on their intended use: data analysis, system maintenance, operational management support, and strategic planning support. The diagram clearly shows the data flows across the aforementioned components, highlighting the transformation of data from various sources into validated data and finally data with quality control used in the models to get computational values. The HIS is implemented in accordance with the concepts of service-oriented architecture (SOA) [9], and contemporary web technologies are used in accordance with the principles of scalability and robustness.

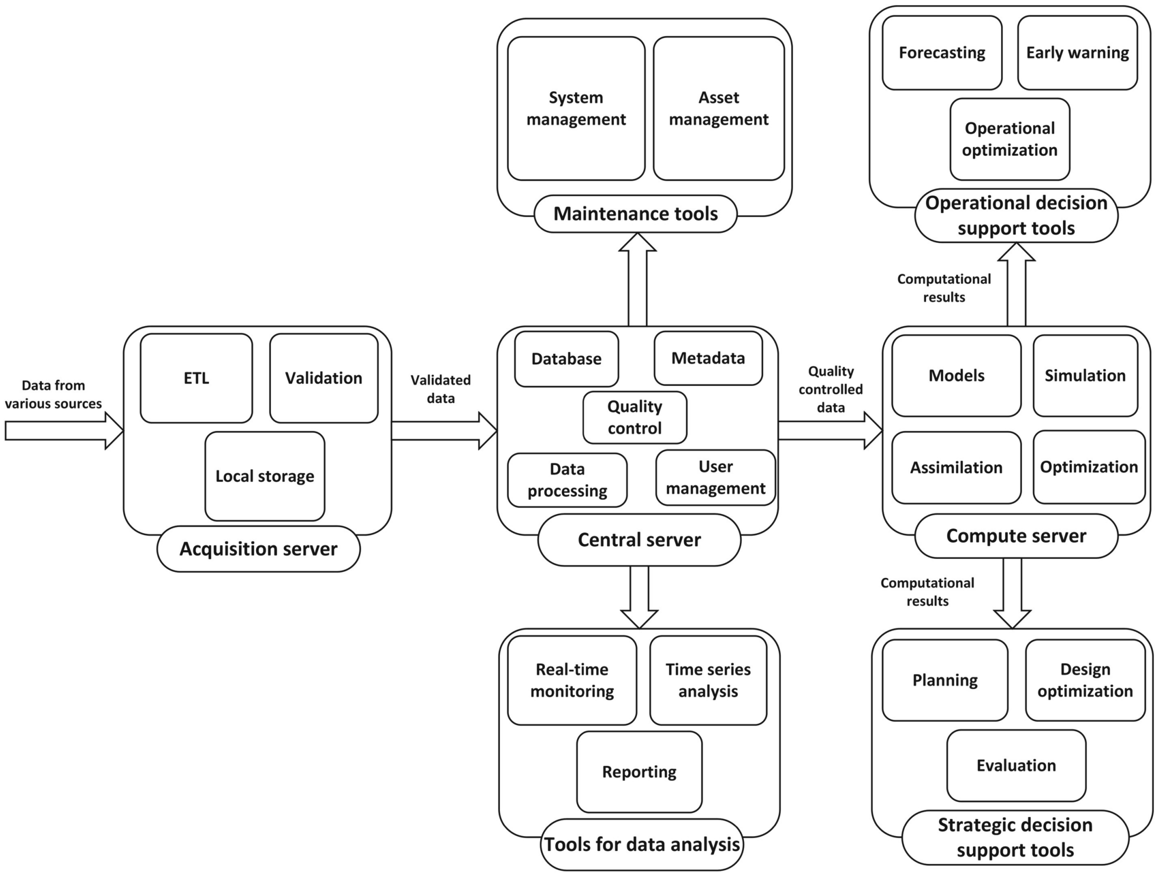

Fig. 1. Structure of hydroinformatics system technology platform.

3.1 Data Management

Users of the platform have access to user and administrator tools where they access data, while processes linked to data management in the HIS take place on the acquisition and central server. The major objective of data management in HIS is to enable data processing and retrieval with quality control information as well as to automatically extract and translate data from diverse sources into data and metadata models defined in HIS. All components involved in data management operations must be effective and dependable for the data to be immediately downloaded and used for calculations with the necessary level of accuracy when it is needed for decision-making.

The acquisition server's role within the system is to gather measurement data as well as pertinent data regarding the system's status. The system can accommodate any number of acquisition servers. Each acquisition server has a data transmission component that connects it to a central server. The foundation of automatic data gathering is the ETL (Extraction, Transformation, and Loading) principle, which enables the blending of data from numerous sources. The ETL process is implemented in a modular and configurable way that makes it simple to adapt to system changes that might arise.

The data validation process is an essential component of the acquisition server, which is a part of the data receiving layer. This procedure indicates that each item of data received is checked before being registered in the local storage. This check yields a data status that may be accurate or inaccurate. This is how the acquisition server's data validation procedure can filter the input data so that only the right data is used by the rest of the system.

All data is downloaded, verified, and then kept in the local data storage. The storage of the data in the local storage is time-limited once it has been transmitted from the local storage to the central server. This means that the data is deleted from the local storage once the configuration-defined amount of time has passed. This is how the local storage provides the central server's acquired data with time-limited redundancy.

The central server, as a key subsystem of the system, plays a central role in the operation of the HIS. It serves as the core component of the data management process. All system elements interact with the central server, which is responsible for ensuring seamless access to its resources, with the central database being the primary resource.

On the central server, the data receiving service is implemented, acting as the interface through which system components can write data to the central database. This ensures centralized control and consistency in data management within the system.

The Technical Data Quality Service is an important component that determines the technical quality of the data in the system. This service utilizes evaluators, which are created by the system administrator based on the characteristics and intended uses of the data. These evaluators assess the value and reliability of the data in the system. To ensure reliability, evaluators need to be applied, and they only require data from the relevant data series for computation purposes. Additionally, the service allows for judging the data's reliability by comparing it with values from other time series.

Users and automated software components can apply their own criteria for interpreting data based on quality evaluation, such as whether the data should be used regardless of quality or only if its quality evaluation is higher than a certain threshold.

Any request to the central server from any component of the system must pass through the access management service in order to confirm the necessary access rights. The system's access privileges have been implemented at several levels. The username and password serve as the initial and most fundamental level of access to the system and, consequently, to the data. This degree of security is present in every user application. Determining registered users' access rights to specific system components is the next level of protection. Determining the right of access to data in the system is the third degree of protection. The definition of rights to data in the central database constitutes the final and fourth level of protection. The measured data may be updated by authorized professionals (experts) and saved with a specific system note in a central database.

All components and supporting systems that use information from the central database have access through the data processing and provisioning service. The data processing and provision service handles all requests for data. Only the original data are stored in the database, and data processing is carried out as requested by the client. In the processing process, arithmetic expressions and data aggregations are permitted, and data quality information must be taken into account. The administrator tools allow for the configuration of all processing parameters.

The central database serves as a repository for all HIS data since it compiles all time series obtained through observation in the system, as well as information on the observation system, documents, and HIS functionality. Graphical layers, time charts, and user accounts are among the functionality information found in the central database. It is possible to track the history of modifications made while using the system because all data are time-referenced.

Observation time series data make up the majority of the core database. The central database enables the preservation of pertinent measurements into a system that is intended to collect and deliver to the user the data captured at various places and systems in the most efficient manner possible.

The central database contains information on the observation and data collecting system, including spatial relationships, measuring equipment features, the state of the measuring equipment, etc. It is possible to track the state of the system across time, from the addition of entities to the system, through changes in attributes, to the archiving of entities, because observation system data are recorded in a central database with a time reference.

The central database also contains the following information in addition to the data listed above: user notes, user data kinds, groups, documents, etc. This makes it easier to evaluate time series data and potential modifications to the measuring device that can result in abrupt changes in observed values or breaks in time series.

The metadata database holds data that accompanies subject data in addition to the fundamental data that is kept in the central database, making it possible to comprehend the data in the central database better. The administration of metadata in the system has been greatly facilitated by the implementation of a metadata model in HIS that enables inheritance via hierarchy.

Data management techniques, whose goal is to provide access to data in a consistent way and with the use of system content made by administrators, serve as the foundation for user applications for data analysis. Particularly, layers and diagrams for reviewing historical data are created, as well as panels for reviewing real-time data. It is also feasible to create reports using information from the central database and information gleaned through their processing.

Tools used by administrators to manage databases and metadata as well as configure software components make up a distinct group. These technologies also make it possible to maintain data on measuring apparatus, which greatly simplifies the upkeep of the monitoring system by users.

3.2 Model and Simulation Process Management

The HIS supports a variety of mathematical models. Although hydrological models are most frequently seen, they are frequently integrated with hydropower and 1D and 2D hydraulic models. It is also possible to use models for the movement of water in materials, groundwater flow, and many other natural phenomena. The nature of the studied system makes the introduction of additional models frequent (e.g., a hydraulic model of flow through karst canals for karst basins). In order for HIS to function, models must be able to communicate with one another and with data collected by the system.

By combining the numerical solver's executable files and model files into a wrapper, it is possible to easily perform calculations with user data. It implements an interface for setting up initial values and conducting computations. Through a wrapper, it is feasible to control the calculation and keep track of the data from the original solver. Reading the results is also viable through the interface, where various post-processing may be carried out before the results are shown in the tools.

The use of algorithms for optimization and assimilation of measured data is made possible using wrappers for conducting calculations in mathematical models. To handle multi-criteria optimisation issues that arise in the management of water resources, the HIS specifically offers the use of a platform for parallel evolutionary algorithms. In order for the optimization results to be accessible at the operational level, it is required to match the division of the hydro potential of the Serbian and Romanian sides with the limitations set out in the regulation on usage of the sophisticated system, as in the case of HIS Iron Gate.

On the same platform, it is also possible to implement algorithms for assimilation of measured data into model states in addition to optimization problems for decision support. This will improve the match between the values of the reconstructed model state and the actual values, which will improve forecasting of the state and output from the model. The service offered by Flood Early Warning System (FEWS) "Kolubara" is one of the most recent instances of assimilation in use. This implementation uses information gathered from the observation network on air temperatures, rainfall, and river course levels to update the coupled hydrological-hydraulic model of the basin in order to provide early warnings and flood warnings.

The compute server, another essential component of HIS, is where all the aforementioned functions for managing models and computations are put into practice. Dedicated high-performance hardware is frequently found inside the compute server, where it is employed to carry out calculations and address optimization issues. If the purchase and upkeep of the High-Performance Computing (HPC) cluster proves to be too expensive for the HIS user, the option of using cloud resources is also contemplated.

3.3 Decision Support Tool

In general, HIS includes user-based decision support tools that allow analysis of measurable data with quality control and computation outcomes in mathematical models to be made in order to make judgments at the short- or long-term levels [10]. Depending on the user's needs and the specific HIS installation, it could only contain tools for operational management or only have capabilities for strategic planning.

Real-time model state reconstruction methods and value forecasts will soon be used in HIS to assist operational management. Short-term planning, expert evaluations, and the creation of notifications on impending events may all be quickly verified by users using tools designed for this purpose. Since it is frequently impossible to measure the values that are important for making decisions directly, these methods may be used to estimate the values, allowing for the informed making of decisions. An up-to-date state of the model may be created using the automatic assimilation process that takes place on the compute server, which allows for the creation of more precise forecasts. The daily production plan at Hydropower Plant (HPP) Iron Gate 1 and HPP Iron Gate 2 is therefore checked in HIS Iron Gate, for example, using these forecast data to check the plan. If the plan needs to be modified, the tool can provide substitute plans or allow the plan to be verified as needed. In the early warning and flood warning systems, another use of the forecast values is the comparison of the predicted values of the level with the threshold or, more accurately, with the actual geometry of the bank and embankment for even more specific alerts (Fig. 2).

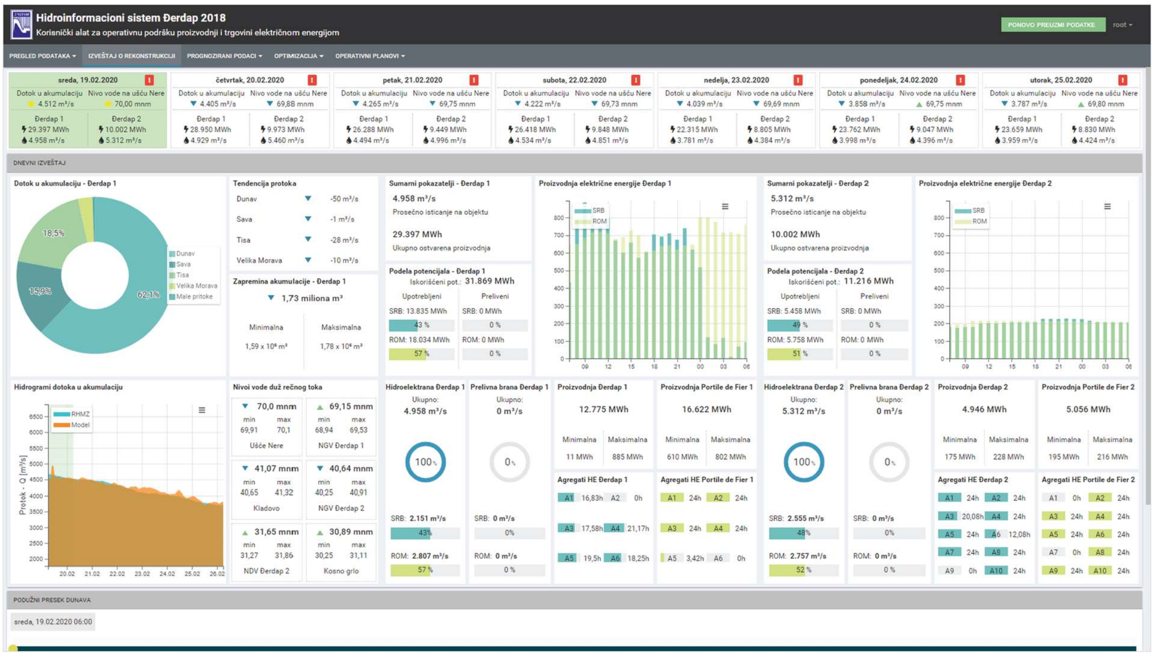

Fig. 2. HIS Iron Gates decision-support tool for operative management.

User tools enable analysis to be implemented over extended periods of time in order to examine the consequences of investments or changes in management rules, which supports strategic planning, or decision making at the long-term level. With the use of

HIS tools, statistical data processing based on lengthy time series may be done, and pertinent hyetographs and hydrographs can be formed in order to produce fictitious situations. As an illustration, evaluate design options using water hydrographs from the last 100 and 1000 years. The tool for analyzing the impact of floods on the roadway and nearshore to help the planning and construction of the Morava Corridor is an example of one of these tools. The program makes it possible to launch a hydrological model, the output of which serves as an input for a 2D hydraulic model. They were utilized to examine the risk areas along the Zapadna Morava riverbanks as well as any possible hazards with the planned road grade (Fig. 3).

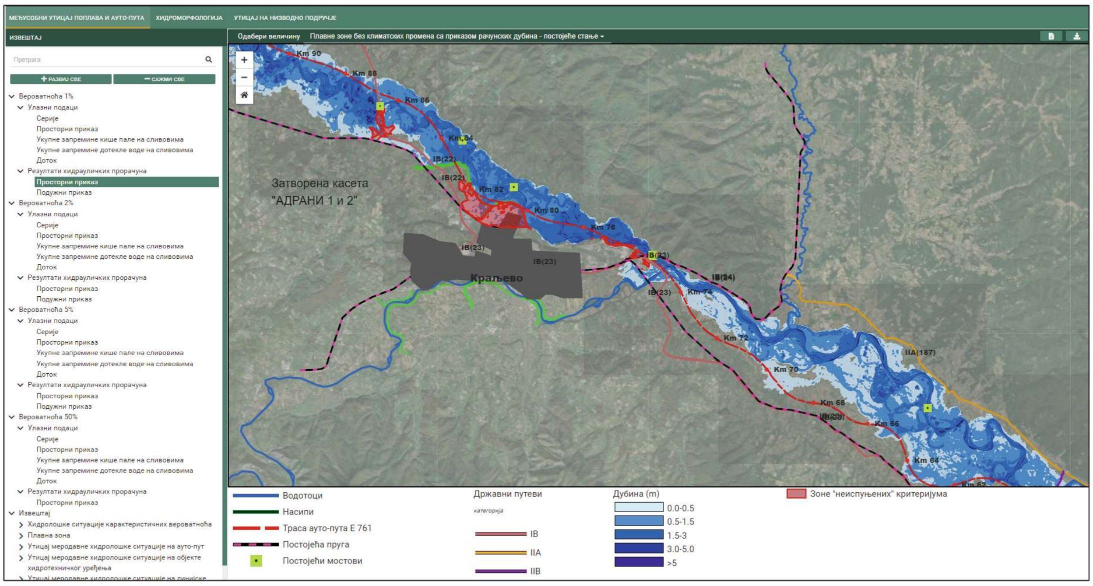

Fig. 3. Morava Corridor decision-support tool. Shades of blue represent the depth of flood waters, while red represents potential hazards in risk areas.

In order to calculate the consequences of investments across decades, mostly hydrological models are used. This is accomplished by accounting for the outcomes of climate models for various scenarios of climate change. Hydropower models then utilize the outcomes of hydrological models to evaluate the effectiveness of various technological solutions. The strategic planning tool in HIS Drina is an illustration of one such instrument [11]. It is feasible to calculate the yearly generation at potential hydroelectric power facilities in the Drina River basin while taking other water users (water supply, industry, etc.) into consideration. The use of models and optimisation algorithms for determining the effectiveness of the management rules for the multi-purpose reservoir is demonstrated by the example of the tool for periodic update of the HIS Prvonek management rules. This tool accounts for changes in anticipated freeboard as a result of potential climate change as well as changes in water usage.

4 Conclusion

Application of a general approach is required in the development of HISs in order to lower costs and increase standardization in implementation across various systems. This is due to the growing need for decision support tools in the management of water resources and the ongoing development of numerical procedures and hardware platforms. It can be argued that the HIS idea described in this work is a good foundation for further development and expansion to additional areas of application in water management based on the presented implementations in real systems. Main areas of application may include advanced flood early warning systems with integrated remote sensing, optimal operational management tools for hydropower and utility companies, and various resilience analyses [12].

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Preface

This book includes selected high-quality peer-reviewed research papers presented at 13th International Conference on Information Society and Technology held on Kopaonik Mountain, Serbia, on Mar 12–15, 2023. In an era where technology disrupts many facets of our lives, the papers included in this issue exemplify the remarkable ways in which information technologies are reshaping our world, driving innovation, and paving the path toward a smarter, more efficient society.

The selected papers represent a diverse range of topics, all connected by the common commitment to explore information technologies as tools for positive transformation. From e-government requirements specification to advanced machine learning algorithms for river water quality management and from the application of artificial intelligence in healthcare to the analysis of financial markets using social media data, these contributions collectively illuminate the profound impact of information technologies on various domains.

One of the several focal points of this special issue is the intersection of artificial intelligence and public administration. Some papers delve into this area, addressing topics such as the role of AI in public administration and business sectors and the adoption of e-contracting and smart contracts for legally enforceable conformance checking in collaborative production. These papers underscore the potential of information technologies to enhance governance, streamline processes, and promote transparency in the public sector.

Another significant theme explored in this issue is the application of disruptive technologies in healthcare. Whether it's the prediction of coronary plaque progression using data mining and artificial neural networks or the risk stratification of patients with hypertrophic cardiomyopathy through genetic and clinical data features, these studies demonstrate how advanced information technologies are contributing to the diagnosis, treatment, and overall well-being of individuals. The use of technology in healthcare is becoming increasingly indispensable, and the papers presented here showcase the latest trends in this field.

Furthermore, this special issue highlights the importance of sustainability and environmental consciousness in our technologically driven society. From estimating solar power potential for rooftops to optimizing wind production forecasting and analyzing hydropower system resilience, these papers underscore the critical role of information technologies in promoting eco-friendly practices and renewable energy solutions.

The paper review process, organized as a single blind, had two stages. In the first stage, the papers were reviewed to be accepted for presentation at the 13th International Conference on Information Society and Technology. A total of 80 papers were accepted for presentation at the conference. The authors had the opportunity to prepare an improved version of the manuscript for these proceedings. After the second stage of review, 48 papers were accepted for publication in the proceedings.

In conclusion, “Disruptive Information Technologies for a Smart Society” represents a collective effort to explore the transformative power of information technologies in diverse domains. We extend our heartfelt gratitude to all the authors who have contributed their valuable research. Also, we would like to thank the reviewers who, with their expertise and comments, contributed to significantly improving the quality of the selected papers. We believe that the insights and findings presented in these papers will not only advance our understanding of the potential impact digitalization may have but also inspire further research and innovation in the pursuit of a smarter, more connected, and sustainable society.

November 2023

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