Mathematical Biosciences and Engineering

http://www.aimspress.com/journal/mbe

MBE, 20(9): 17096–17115.
DOI: 10.3934/mbe.2023762
Received: 06 June 2023
Revised: 31 July 2023
Accepted: 16 August 2023
Published: 31 August 2023

Review

Open interoperability model for Society 5.0's infrastructure and services

Roman Gumzej* **and Bojan Rosi**

Faculty of Logistics, University of Maribor, Celje 3000, Slovenia

* **Correspondence:** Email: roman.gumzej@um.si; Tel: +38634285314; Fax: +38634285338.

Abstract: As the Internet of Things (IoT) is considered the foundation of digital transformation in everyday life, the Industrial IoT (IIoT) is considered its business counterpart. Together with the Physical Internet (PhI), they represent the foundation of smart production and logistics as part of the new digitized Society 5.0. Smart grids of different kinds with applications, ranging from power distribution to transportation, represent the infrastructure of smart cities and communities. Like with the PhI, they rely on the acceptance and integration of their services to fully unleash their potential. Hence, apart from the open interoperability model, which enables the interoperability and operational transparency of the IoT and IIoT, consistent design and development of their diverse augmented services is crucial for their wider acceptance as well as their safe and sustainable utilization.

Keywords: Internet of Things; smart production; smart logistics; smart governance; services integration

1. Introduction

We have been living with the notion of smart cities and communities for about a decade and we are now confronted with many more or less "smart" devices and solutions to underline this fact. At first sight, the integration of these smart systems may seem pretty straightforward. Since they typically provide many types of data exchange platforms, one may claim that they are not called smart for nothing. However, if we take a closer look, we see a number of individual smart solutions, each serving its own purpose, with few or no interconnections at all. For example, smart street-lights may be quite energy saving in less busy streets, while still providing sufficient illumination when it is needed; however, they mostly operate independently. Another example are smart information tables that notify drivers of the number of free parking spaces at some specific location. They may work independently or provide additional information on less occupied parking spaces nearby as well. What about smart weather stations, which provide information on current weather? They may act as smart sensors, transferring their information through websites to be visible online as well as on-site. However, when we combine these services, they may provide a smarter parking solution, offering drivers the best parking options while also considering early warnings for bad weather situations, as well as directing them to better-protected parking spaces (e.g., garages). Depending on the weather and traffic situation, they may also provide emergency warnings about incidents and appropriate directions to allow for safer travel. A similar case of incident prevention can be observed in wildfire detection [1].

Apart from the aforementioned solutions, various smart solutions have been devised for application in different areas, like e-commerce, e-logistics and e-governance. When they include smart sensors, they are said to be based on the Internet of Things (IoT). In this case, some background service collects their data to assess the current situation and predict future situations, as well as coordinate their actions. For instance, in smart logistics, the Physical Internet (PhI) background service provides smart container handling and automation of supply chain operations [2].

Since smart devices and solutions operate on different integration levels, like with the Internet, an Open Systems Interconnection (OSI) stack is needed to enable the interconnection and integration of smart devices with smart services and applications. There have been different approaches to achieve this goal (see [3, 4]). In well-controlled environments, like under the conditions of smart production, this has already been largely implemented in the form of the OPC Unified Architecture (UA) standards and the Industrial IoT (IIoT). In smart logistics, the Open Logistics Interconnection (OLI) model [5] has been introduced. The Open Interoperability Model (OIM) of smart cities and communities, however, is still being shaped. Since it shall encompass all of the previously mentioned smart infrastructures and services, it introduces common terms to integration technologies. Because of the variety and inherent complexity of its underlying smart environments, its definition is the hardest and naturally comes last.

1.1. Challenges

Due to the aforementioned complexity of smart environments, one may claim that the integration of smart city infrastructure and services is not simple, since otherwise, we would all be living in smart cities and communities with strongly connected and artificial intelligence (AI) supported services by now. Everybody would know their place in the society and the society itself would prosper due to people's continuous innovation, which is referred to Society 5.0, or Innovation Society.

Everybody knows why this is not the case. For as long as there are good places to work and good places to reside, not being one and the same place, people will always strive to change their environment instead of improving it, and they will be preoccupied with this. Some call this phenomenon the driver of economic growth. However, a better description would be the creation of demand. Although, obviously, this is not a desired state of society, this article is not about criticism. Rather, its aim is to encourage diversity and provide means for inclusion by further elucidating the concept of an OIM of Society 5.0.

The development of minimal interoperability mechanisms (MIMs) [6] is an important first, but not the ultimate step in this direction. As illustrated in this article, not only a catalog of smart devices and services is necessary. The smart devices and services need to be able to interact and collaborate with each other as cooperative autonomous systems and their intelligent agents must exhibit smart behavior. The levels of interaction and communication may be diverse, depending on their target area of use and integration level. Hence, appropriate open interconnection models should enable their interoperability.

As they already exist in smart production and logistics, there is a need to define additional OSI stacks for the distinct services of Society 5.0, as well as an OIM to enable their integrations.

1.2. Contributions

Since, despite many attempts in this direction, a comprehensive overview is still missing, in this article we shall provide an overview of the technologies involved, the OSI models and the integration methodologies to devise interoperable smart services within the OIM, based on our experience. It is worthwhile, considering the fact that by fulfilling it, our society would be much more resilient against different types of crisis, like the recent epidemics, wars, earthquakes, droughts and wildfires. Since the distribution of wealth and resources would be more balanced and readily available when needed, there would be no more need for wars, environmental activism, or even armies to protect ones from enemies – just some police to end an occasional bar fight and emergency assistance teams to provide first aid in critical situations. To enable the development of such an inspiring and safe environment, smart city and community infrastructures should be integrated by smart services, empowering digital citizens to use them via their smart devices in ways that best suit them.

The layout of the article is as follows. First, a review of the current state of transition from Society 4.0 to Society 5.0 is given. Then an overview of extended reality (XR) services and their typical applications in different smart environments is given to give an overview of this research from the citizen's perspective. In the following section, the infrastructure and services of Society 5.0 are elaborated and categorized according to their areas of use. Next, the interoperability mechanisms of the aforementioned services are discussed. This is followed by guidelines for building smart applications and services of Society 5.0, to enable their integration and sustainable use. As a conclusion the different aspects of the OIM of Society 5.0 are summarized and an outlook is given.

2. Transition to Society 5.0

As indicated in [7], Society 5.0 represents the most all-encompassing and profound change in human society since the Industrial revolution. Through automation, dematerialization, digitization and "servitization", it introduces new foundations to economic and political life (see Figure 1). These concepts form the core objectives of newer organizations and companies, while the old, powerful and well-recognized organizations are in decline and reorganization. Although happening in the cyberworld, these changes are very real. They result from the birth of new technologies that then become mature and released in record time. These technologies are characterized by digitization and dematerialization. Although still struggling with bureaucratic hurdles and spatial limitations, they are in ascent and shall prevail.

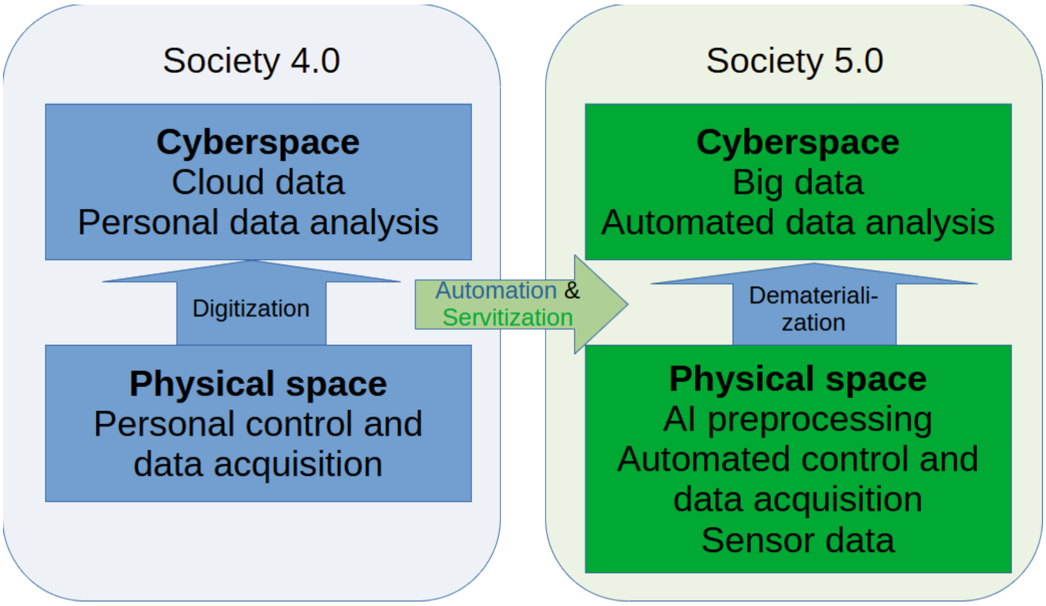

Figure 1. Transition from Society 4.0 to Society 5.0.

Different studies have revealed the all-encompassing nature of the digital transformation taking place in Society 5.0, starting with Industry 4.0 as a metamorphosis of all industrial components with the help of strong digital support. As pointed out by Kravets et al. [8], these changes and the resulting solutions are human-centric, i.e., they put the user at the forefront and provide him/her with services to use at their convenience. It is a new paradigm for a society that balances a human-centered approach and technologies based on cyber-physical systems and AI to improve the quality of life of humans in spite of the challenges. Just as Industry 4.0 involves a digital transformation of every industrial perspective of society, Society 5.0 encourages a digital revamp expanding across different tiers of the community [9].

In the past few years, the aforementioned challenges have been addressed by the Internet of Things (IoT) as well as tracking and tracing technologies. Various partial solutions stemming from e-business, telemedicine, urban mobility, parcel delivery and similar services have been designed. Recently, intelligent logistics systems (iLSs) have been introduced, and they incorporate mutual cooperation and automated cohesion in e-commerce and smart logistics environments through the use of intelligent agents [2]. Due to the high diversity and inherent complexity of the application areas, smart services are increasingly being classified as either smart production and logistics services or smart governance. Smart governance refers to the smart infrastructure and services of smart cities and communities. As these two types of smart services coexist in the same geographical location, they are of course intertwined and sometimes it is difficult to tell them apart. Some examples are given below to illustrate this fact and provide a brief overview of the state of technology.

2.1. Smart production and logistics

In smart production and logistics environments, the existing and newly developed transport and warehouse management systems, as well as e-commerce applications, are being integrated [10].

Modern vertical Platform as a Service (Paas) (e.g., Elemica (http://www.elemica.com)) and horizontal Software as a Service (SaaS) (e.g., Salesforce (http://www.salesforce.com)) supply chain integrations are enabled through web interfaces and cloud-based delivery models. They provide e-commerce solutions in most contemporary business cases. The newly developed agent based delivery models offer greater flexibility in terms of transparency, scalability, interoperability and maintainability through intelligent web and XR interfaces. Since they represent the key properties of smart and sustainable production and logistics, they have become the next hot topic on the research agenda.

In response to the expanding e-business market, last-mile delivery (e.g., [11]) is being improved by the appropriate management of urban consolidation centers [12,13] supporting it. While the benefits of introducing these centers are obvious, there is still some dispute about the format and mode of delivery. In this context, the important role of the PhI in last mile delivery is being highlighted. As an important background service for parcel delivery it promises better coordination of shipments, a smaller transport CO_2 footprint and less congestion in the city centers.

2.2. Smart cities and communities

With smart city applications, the city infrastructure and services are being integrated by IoT technology. By its introduction, they can be managed and made available through web services and mobile apps (e.g., SmartAppCity (https://www.smartappcity.com/en/)). Smart city logistics is being extensively investigated to render economically, ecologically and socially excellent solutions that would reduce city traffic while enabling efficient mobility of persons and delivery of goods. The main constraints and supporting technologies have been highlighted in [14, 15]. In this way, intelligent sensor networks have been identified as key traffic information source [16]. Big data and data mining have been identified as key technologies for managing journeys, delivery trucks, toll collection, public transport, road safety and shared traffic information [17]. The use of intelligent traffic control, co-modality and modular containers shall enable faster and more efficient transport of people and goods in urban areas [18].

IoT and big data technologies have been integrated with e-commerce and smart logistics applications to form sustainable solutions for goods replenishment within and between smart communities encouraging cross-border cooperation [19, 20]. Hybrid web and agent-based systems have been proposed to facilitate smart logistics services through the integration of intelligent distribution centers with e-commerce application environments [21–23]. They have been proven to positively affect the indicators of organizational efficiency in smart logistics ecological supply chains [24, 25].

2.3. Smart technologies and security

As with the aforementioned e-commerce and smart logistics solutions, interoperability is also a key characteristic of smart city solutions, and it will be crucial when integrating the smart environments of Society 5.0. By the integration of intelligent agents technology, big data analytics and AI methods, local, regional as well as cross border optimization of logistics networks can be accomplished [19, 20, 22, 24, 26, 27]. These are the key technologies that shall enable the integration of various smart environments through a consensus on common concepts that encourage global optimizations.

Considering the confidentiality, integrity and availability of the information related to smart services, several issues have been highlighted. Besides data encryption, data mining technologies for big data logistics [28] as well as advanced security analysis and transaction supervision have been investigated to assure the security, control and operational efficiency of the underlying electronic transactions [20].

3. Infrastructure and services of Society 5.0

Society 5.0's infrastructure and services feature its main application areas, i.e., smart production, smart logistics and smart governance, as well as its characteristic technologies, i.e., big data, data mining, forecasting, digital twins and some form of XR. As pointed out in Figure 2, iLSs represent the central concept of a digital counterpart of the various entities involved to build an ecosystem of intelligent agents, i.e., cooperative autonomous systems, in any smart environment. In combination with the pertaining background services (e.g., yellow pages in e-commerce, PhI in smart logistics, etc.) iLSs form the foundation of the open integration platform for their collaboration [2].

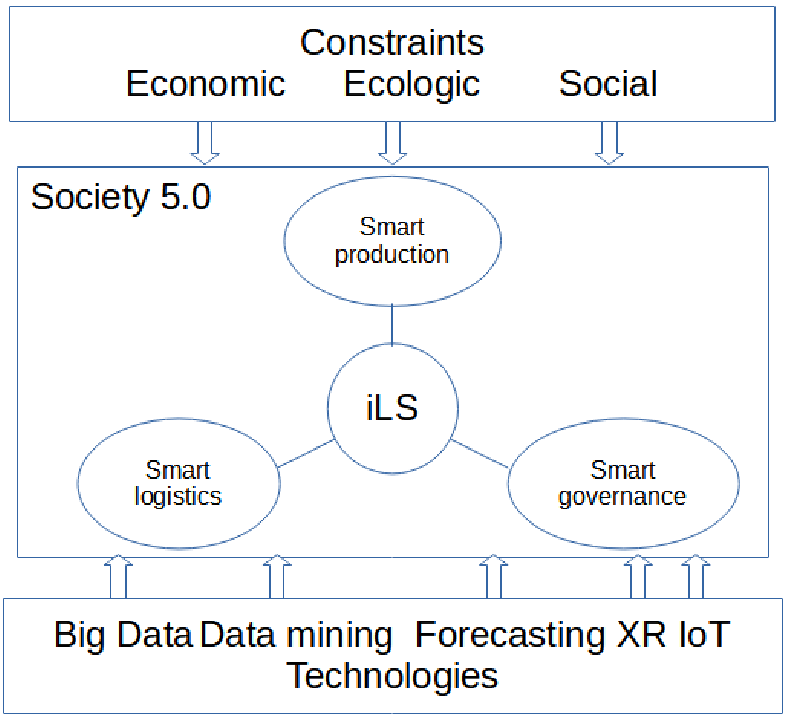

Figure 2. iLS in Society 5.0 [29].

For instance, according to the PhI OSI model (Figure 3), iLSs represent intelligent agents that realize augmented logistics (AL) services across the PhI. They are accessible to other iLSs via the PhI background service, as well as via their client's XR interfaces. The PhI domain server acts as a broker between iLSs, representing collaborating parties in their supply networks. PhI networks represent one of the Society 5.0's (see Figure 4) overlay networks. Analogously, the yellow pages background service acts on the application level as an e-commerce domain server. The iLSs involved in supply chain operations across the PhI interact with both to fulfill their tasks. Similar domain servers shall support all distinct application areas in Society 5.0. Thus, the smart production, logistics and governance subdomains shall build a coherent Society 5.0 ecosystem of intelligent agents. Through their interaction and collaboration, they shall fulfill their functions in a consistent and socially aware fashion.

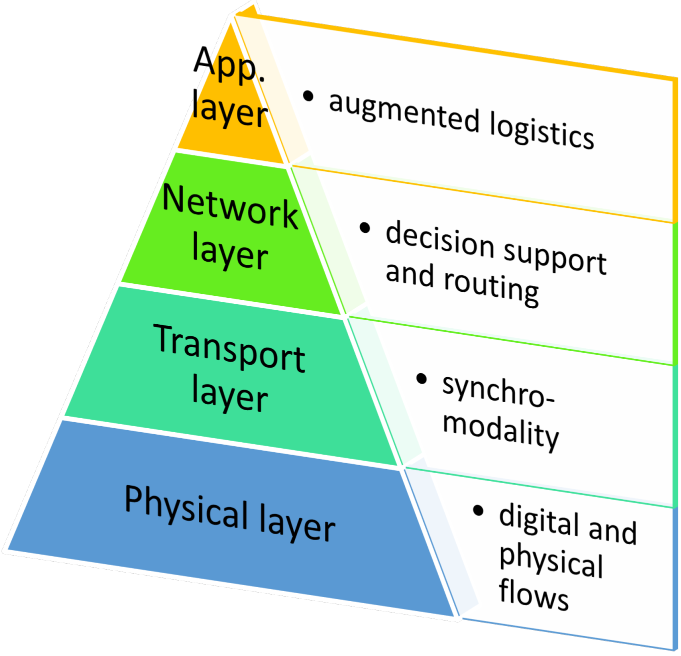

Figure 3. PhI OSI model [29].

To become part of the Society 5.0 ecosystem, each smart infrastructure element (iLS) must at least implement the functions of the (cyber-)physical and application layers of the respective OSI model (see Figure 3). In the case that the element belongs to a grid, its transport layer properties need to be defined as well. In addition, if the element is involved in any load-balancing operations, its network layer services need to be defined. Finally, if the element is to interact with human operators, its XR application layer interfaces need to be defined, to represent the various application specific interfaces for its services. As already pointed out in [2], iLSs shall receive high level instructions from their users via their XR interfaces and report back with the results. While fulfilling their tasks, however, they will mostly communicate among each other rather than with their users, demonstrating autonomous behavior.

As mentioned in the introduction, most smart infrastructures and services have been planned and implemented independently. This has some benefits, but also many downsides. While the latter is usually not obvious from the beginning, over time, the disadvantages become more prominent, since these systems require maintenance. In order to receive proper maintenance, they have to be managed consistently and transparently. While the presented framework supports both, there is more to it, since appropriate maintenance and training is required to operate them in the long run. A successfully proven approach to such maintenance is the integration of integrated logistics support into their life cycles (see Figure 4).

4. Open interoperability model of Society 5.0

In Society 5.0 new technologies and business models are being created based on its smart logistics, production and governance systems. Among others, they include digital twins, supply chain integration, mobility and production as services, PhI hubs and containers, e-health and e-government solutions. From the perspective of their users, i.e., the digital citizens, the OIM of Society 5.0 reveals itself as an ecosystem of digitized resources, readily available to accomplish complex operations through their seamless collaboration.

In order to create an OIM of Society 5.0 infrastructure and services, they need to be orchestrated, i.e., categorized, layered and comprised by their domains' background services. As with the smart logistics PhI OSI model, the corresponding layers (see Figure 3) with their distinct domains [2] need to be included:

- global domain (world),
- regional domain (region or continent; e.g., European, Asian, Pacific, etc.), and
- local domain (city, county or state; e.g., Maribor, Styria, Slovenia).

The global domain is used to define global interoperability and collaboration principles. It shall also be used to define and study the criteria that are needed to incorporate economic, social, and ecological constraints into the global Society 5.0 ecosystem. The regional domain is used to strengthen digital and physical interconnections and enable synchromodality. The local domain is used to deploy smart infrastructure solutions, representing Society 5.0 entities, featuring Society 5.0 services. It represents a platform on which new business models, which are emerging as a result of the introduction of the aforementioned new technologies and service models, are deployed. Their implementation plans include the application and evaluation of concepts and technologies, such as intelligent agents and multiagent systems, the IoT, data analytics, big data, autonomous systems, the PhI and advanced planning systems as well as the virtualization and dematerialization of assets. They represent the elements of Society 5.0, and they comprise layered domains of smart logistics, smart production and smart governance overlay networks (Figure 4).

It is up to the implementation logic of smart solutions to define how the individual entities of this ecosystem fulfill their functions, interact and collaborate with each other. Hubs and spokes have a special role in this architecture, since they represent the connections between the distinct nodes of the overlay network. Domain services enable their discoverability within and between different overlay networks as well as load and flow balancing within the networks of Society 5.0 (Figure 4). For instance, the PhI, representing a collaboration and distribution network of smart logistics, is also basically composed of hubs and spokes. Since its definition encompasses all domains and OSI layers with the PhI background service as the domain server, it can serve as a reference model for implementing other Society 5.0's infrastructure services.

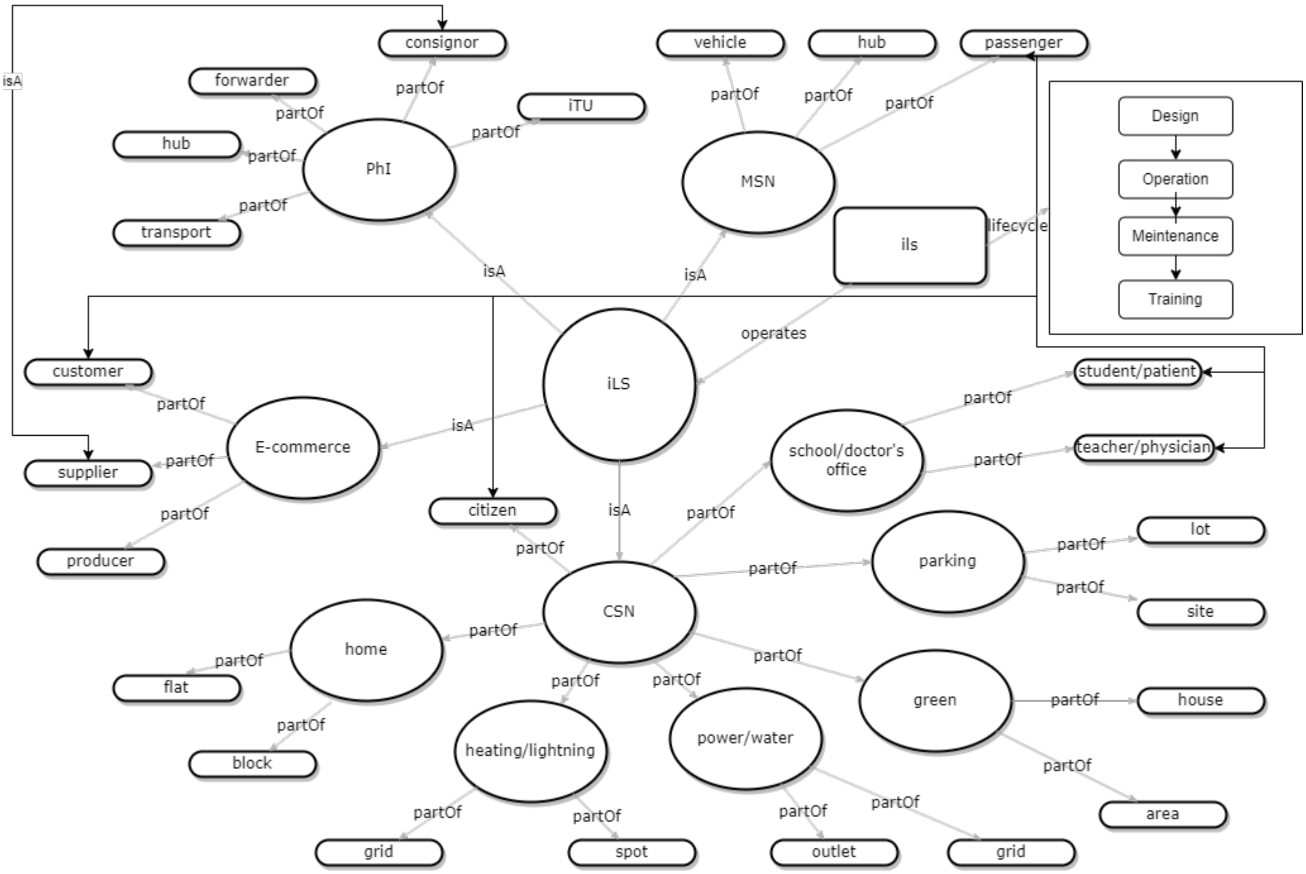

Figure 4. Society 5.0 overlay networks.

The OSI model of any Society 5.0 infrastructure service, i.e., its service stack (Figure 5) hence encompasses the following layers:

- Application services layer (XR, domain services),
- Network layer (smart grid; e.g., the PhI),
- Transport layer (smart grid),
- Cyber-physical layer (iLS based on IoT, IIoT).

As one can deduce from the above considerations, the service OSI model resides on top of the corresponding IoT OSI model with the IoT application layer and cyber-physical layer of the service stack as connection points (Figure 5). Simpler services only require the definition of an additional application services layer to create unified interfaces among the pertaining actors and make the service available to its users. This is sufficient to provide also its operators with appropriate tools for maintenance of the service through IoT protocols. Services that require network management, load balancing and intermediate storage of flow items need to incorporate the additional two smart grid layers that provide for appropriate addressing and background services. The background services are application specific; however, through their basic functions, they need to enable intra- and inter-network communication and collaboration. This should ease the transition from the automated Society 4.0 to autonomous Society 5.0 and make it more transparent.

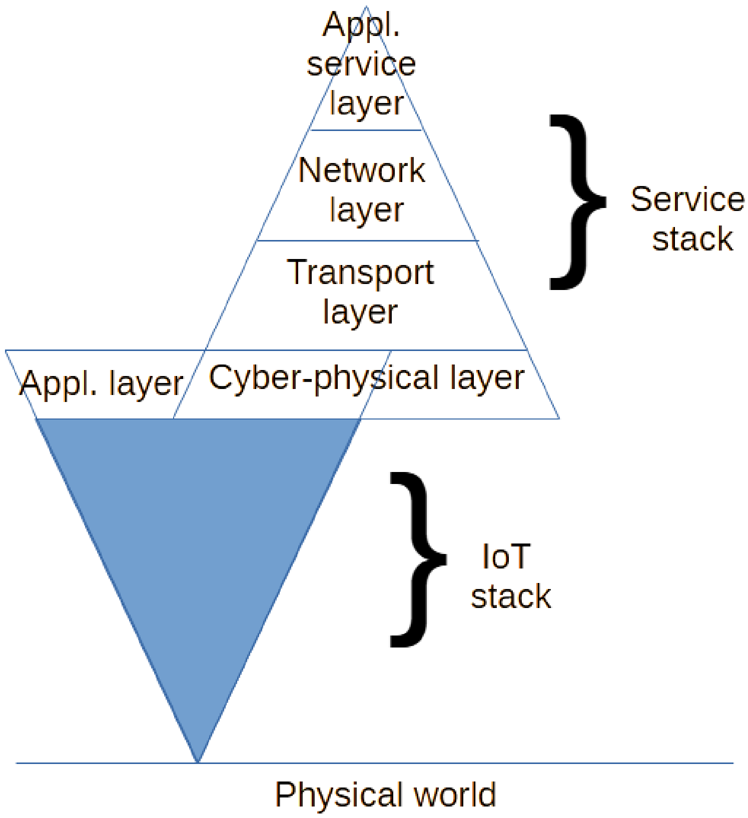

Figure 5. Society 5.0 OIM stack.

5. Augmented Society 5.0 services

Society 5.0 services aim to optimize the performance of heterogeneous systems composed of several independent but inter related sub-systems (e.g., authorities, producers, consignors and citizens) at different levels of decision-making (strategic, tactical and operational), while also satisfying their objectives and constraints (social, environmental, economic, safety, liability, etc.). They go beyond the state-of-the-art of Web 2.0 services in a number of areas, including the PhI, iLS integration, optimization by AI methods, implementation of OIM models for different smart application areas and basic application-specific services, development of new XR interfaces and assessment of their quality of service (QoS).

As AL resides at the top of the PhI OSI model, similar augmented production, community, mobility services, etc. shall enhance individual Society 5.0 application areas with their distinct service networks. They shall improve the level of innovation in smart governance, production and logistics management systems by providing a digital twins ecosystem [30] in which all of their services are treated equally. Appropriate iLS interfaces shall provide for (inter-)connections in the Society 5.0 cyberspace through which the different stakeholders will be enabled to accomplish their goals and collaborate. They shall be accessed through the use of the domain service that resides at the top of the domain's OIM hierarchy and acts as a broker for the various service requests posted by individual iLSs representing the corresponding Society 5.0 stakeholders. By supporting regulators, suppliers and customers alike, they significantly advance the knowledge in the areas of decision science and operations research, as well as remove barriers to the optimization of independent and autonomous entities with inter related and inter twined impacts. Interoperability, data mining and the decentralization of functions will allow the results to be used not only within one domain, but also between domains.

The role of the service domain gateways is to route iLS requests through the distinct overlay networks of the Society 5.0. Their functionality is identical to that of the Domain Name System (DNS) service of the Internet. It routes the agent communication language (ACL) messages within and between the overlay networks according to the types of iLS involved and the services they request. As the iLSs represent the distinct cyber-physical systems involved, their domains shall be used as primary differentiators between their networks. If, according to the protocols involved, a service from another network is required, this shall be evident from the message header; also, the service request is appropriately routed. Regarding iLSs representing coordinated autonomous systems, the domain services shall reside at the interior and exterior gateways interconnecting their respective networks.

5.1. Smart logistics

To successfully integrate AL services over the PhI, its four basic OSI layers (see Figure 3) need to be defined to form the OLI model [29]. In order to enable the AL services at the PhI nodes, respective iLS models have been aligned with them and the associated PhI OSI model. This enables their physical, operational and transactional interoperability.

In smart logistics, the iLS concept promotes a novel approach to AL through the transformation of logistics resources into services, and by treating them as commodities. Through their iLS intelligent entities in the PhI, they not only communicate with or on behalf of persons and organizations, but, foremost, they communicate with each other to fulfill automated logistics processes through their collaboration. To give an example, in [29, 31] automated smart container routing, tracking and condition monitoring can be observed. In the PhI, the containers themselves, as well as their forwarders, carriers and consignors, represent active participants, i.e., iLSs in the process of moving cargo along the PhI distribution network. Here, the PhI hubs take over the role of distribution centers and the responsibility for appropriate cargo routing. The PhI background process ensures that the containers arrive at their destination as efficiently as possible.

5.2. Smart production

To enable the implementation of an open interconnection model in production environments, the OPC UA stack has been defined. In combination with the IIoT [32], it yields an appropriate digital twins environment for industrial setups. Through their open interfaces, they yield virtualized resources (production cells/lines/plants) which manufacturing execution systems (MES) applications can control, monitor and optimize. Since the virtualized resources in industrial environments are accessible via the cloud, they can be efficiently managed by cloud-based Enterprise resource planning (ERP) systems at different levels of decision making.

In smart production, the production cells or plant's iLS takes over the roles of the suppliers in the e-commerce network. They exchange ACL messages with their customers to fix deals on the e-commerce network [33]. In the process, they address the yellow pages background service that takes over the routing of the requests for quotes to appropriate producers, considering their portfolios in the e-commerce domain registry. As a result, the products are produced for order and delivery on the PhI network on the promised date.

In relation to the PhI, each individually managed production unit shall have its associated iLS representing its capabilities and interconnections [29]. When requesting outside resources, their iLS will automatically interconnect with iLSs of related entities. They shall interconnect with their partners through e-commerce networks. After that their orders will be fulfilled through the PhI, as described above, where the roles of the supplier and customer will be taken over by the roles of the consignor and consignee, respectively. Of course, the other way around, each plant's iLS will also receive and service requests from its clients.

The experience from the introduction of the OPC UA and IIoT leads to the conclusion that an ad-hoc approach to engineering smart production solutions does not pay off. In the absence of proper standardization, application-specific standards must be applied to achieve sufficient service quality levels. In addition, to ensure appropriate levels of safety and security, additional standards [34] may need to be applied. In spite of all this, these standards are usually still insufficient to provide for seamless interconnections between plants, hence the benefit of the definition of the OIM, which combines smart production with smart logistics.

5.3. Smart governance

With the advent of Open and Agile Smart Cities (OASC) MIMs [6] a similar standardization and virtualization effort to the OPC UA stack has been commenced for smart cities and communities. They shall play a significant role in smart governance, especially for the efficient management of city infrastructure and mobility providers. The introduction of MIMs is the first step in this direction; however, it is not sufficient. As with smart logistics and production, their OIM models need to be defined as well [2].

From the user's perspective, city infrastructure shall be made readily available through XR interfaces, which shall enable their users (e-citizens) to accomplish their objectives (e.g., find parking, make a doctor's appointment, use quickest method of transportation to a final destination, manage telecom/power/water supply connections, etc.). From the governmental perspective, the unified representation of smart city resources shall allow city management to plan ahead, perform inspections, provide maintenance and offer e-governance services to smart city inhabitants.

Smart cities operate diverse overlay networks, sharing the same space and time, i.e., community services network (CSN) and mobility services network (MSN) (see Figure 4). Their resources may be independent (e.g., sewer system, power grid, etc.) or shared (e.g., road, public transport and parking infrastructure). For load balancing and contingency planning it is important to unify the management of these networks. For example, maintenance of city infrastructures often requires certain parts of the road network to be closed. To foresee the impact of such closures and plan appropriate bypass routes the data from smart traffic counters and public transportation plans need to be considered [35]. Only by smart traffic management can one prevent traffic jams of higher proportions.

In smart governance, the distinct public services constitute several distinct networks, facilitating the servicing and movement of people and goods:

- CSNs (e.g., schools, hospitals, power grids, sewer systems, etc.),
- MSNs (e.g., public transportation, smart mobility solutions, etc.).

In principle each of them requires the definition of a distinct domain service with all of its OIM layers. Some community services, like e-learning and e-government, have a simpler structure. They only require the definition of the cyber-physical and application service layers with their domain servers (cp. yellow pages background service). Smart mobility solutions, on the other hand, require the definition of all layers (cp. the PhI background service). Services that encompass local, regional and global domains also require internal (local) as well as external (regional and global) gateways at each level, connecting the sub-domains to each other and facilitating their interaction and collaboration.

6. Design guidelines for the implementation of Society 5.0 services

Based on the above considerations the necessary steps for the development of new smart solutions in Society 5.0 are:

- definition of a digital twin (iLS), based on its IoT/IIoT representation, i.e., its properties (ID, type, role, state and other relevant properties, e.g., dimensions, location, temperature) and limitations (thresholds on the stated values of their properties);
- definition of its behavior model, i.e., its inherent functions;
- definition of its communication model, i.e., its capabilities and vocabulary;
- definition of its collaboration model, i.e., its connections with other iLSs in order to fulfill its functions;

These are the cornerstones of any smart service in the Society 5.0 ecosystem. As a merit of its successful implementation, its QoS should be monitored and fine-tuned. The listed basic steps are necessary to implement, even for the simplest smart solution. Of course, more elaborate property descriptors, as well as more complex behavior, communication and collaboration models, shall allow for scalability of the designs to describe very complex ecosystems of cooperative autonomous systems. They can benefit from cloud-based knowledge-sharing in terms of Web 2.0's ontologies. To maintain and use this knowledge, appropriate semantic web technologies (e.g., RDF, RDFS, OWL, SPARQL, SKOS or SWRL) may be used [29].

In order to define an OIM of a complex Society 5.0 infrastructure service the layers of its corresponding OSI model need to be the aligned with the infrastructure entity's iLS model:

- In the cyber-physical layer, the digital twin is formed by defining the entity's properties and functions, i.e., its data and behavioral models.
- In the transport layer, the overlay network of the service is defined by naming the interconnections between related nodes and including them with the digital twin's ontology.
- In the network layer, the routing and load balancing in the defined overlay network is performed by a background service that is in charge of the digital twin's collaboration in the network (e.g., moving objects between nodes along the PhI); here, the corresponding protocols need to be defined.

- In the application service layer, the interfaces of the new service are defined; upon creation of a newly defined digital twin's entity, the new service is registered with the domain service (e.g., yellow pages service) to be accessible by others via its interfaces.

The application layer of the IoT OSI model allows for implementation of SaaS solutions, enabling the monitoring and life-cycle management of these solutions. However, for the implementation of ecosystems of cooperating Society 5.0 solutions this is not sufficient. Hence, one may consider the definition of active and cooperating participants in Society 5.0 infrastructure services i.e., iLSs to be an upgrade to the existing IoT/IIoT stack where the IoT application layer and service's cyber-physical OSI layers meet. The joint definition of the IoT and service's OSI stack layers represents the OIM (see Figure 5) of Society 5.0 infrastructure services and enables their interoperability. To avoid any misconceptions about the relations between a digital twin, its network and the role of the domain service they are further elaborated below.

6.1. Digital twin

Since the digital twins were initially implemented by pairing physical systems with digital control systems, to function in their physical environment while also being connected to the Internet. Hence, they were initially called cyber-physical systems, before by their widespread use and enhanced inter-connectivity the term IoT was introduced. This somewhat more descriptive abbreviation characterizes the fact that, through digitization a physical entity (i.e., a device, asset, plant, store, institution, etc.) is assigned a representative iLS agent in cyberspace. While most of their QoS properties (i.e., timeliness, correctness, availability, reliability, integrity, maintainability, safety and security) can be realized through their rigorous design, some require conformance to appropriate industrial standards.

To ensure that their QoS properties are respected and properly addressed, it is important to align the modes of operation of the iLS and the cyber-physical system that they represent:

- passive (data acquisition) cyber-physical systems are represented by simple reflex agents; they keep track of their environment's parameters; they can establish a knowledge base based on the acquired parameters that they gradually refine for use by the back-end information system and make it available on-line as a service or through their web-portal; this makes them simple reflex learning agents, since they do not directly affect their environment.
- semi-active (adaptive reaction) cyber-physical systems are represented by model-based reflex agents; based on their inputs, they fine tune their behavior model to better fulfill their functions in the given environment; depending on the model complexity they can also maintain a knowledge base; this makes them semi-active learning agents since they adapt their behavior according to changes in their environment and thus indirectly affect their environment.
- active (adaptive control) cyber-physical systems are represented by goal- or utility-based active agents which, based on their monitor-analyze-plan-execute (MAPE) feedback loop functions, perform an active role in their environment; they can also maintain a knowledge base (MAPE-K), meaning that they can learn by doing; this makes them active learning agents, since they directly affect their environment based on the knowledge they possess and the recent inputs from the environment.

Since the technologies involved in iLS implementation include intelligent agents and ontologies, which represent the foundation of knowledge management, this forms the basis for the introduction of AI-supported decision making in their autonomous behavior. As may be expected, higher levels of environmental impact require higher levels of safety integrity and security [34]. Currently, more research effort is being devoted to the development of autonomous systems for safety-related applications. For in-field use, only those systems, which have been approved by humans to be free to the greatest extent possible from safety-critical design errors, can be certified as safe [36].

6.2. Network

To enable interconnections between cooperating iLS agents and their coordinated actions, they may form overlay networks. Different overlay networks shall represent distinct Society 5.0 service networks (Figure 6). The iLSs belonging to the same network should be linked by appropriate hubs and spokes to manage the flow of entities (e.g., passengers, smart containers) between them. Network management and maintenance should be enabled by the network's background domain services. Apart from their discovery in the cyberworld, they shall assist iLSs of the same or related networks in forming short, local and far, regional/global links among them.

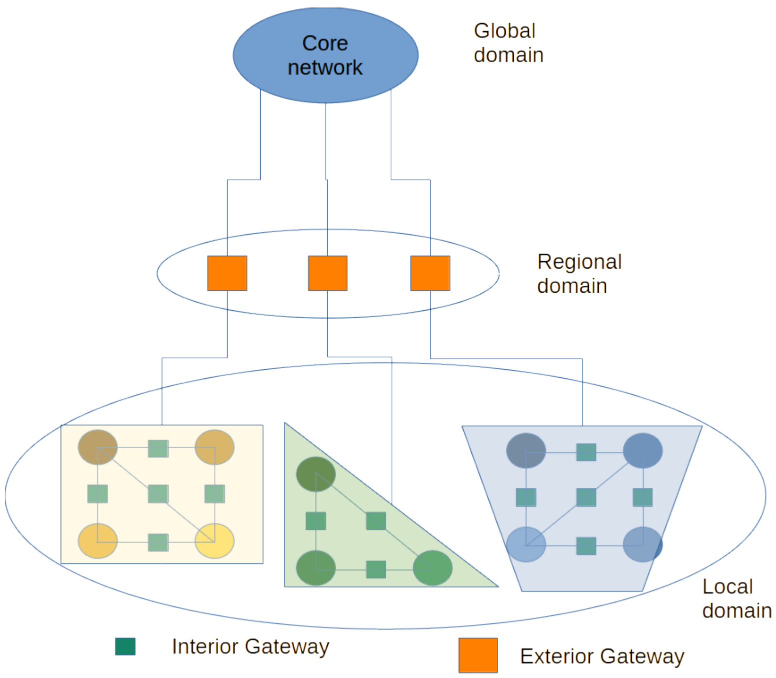

Figure 6. Society 5.0 domain networks hierarchy.

The domain service in the cyberworld provides a dictionary of entities belonging to the same overlay network (e.g., traffic, public transportation, electric grid, etc.). They are hosted by gateways representing web servers at the local, regional or global domains. Establishing short local links via the service may be quite straightforward since the respective requests in the form of ACL messages are handled by interior (local) gateways. On the other hand, establishing far regional/global links requires the appropriate layering of domain services and the involvement of exterior gateways for message routing. These links involve intermediate hubs that represent regional/global domain servers. In the physical world, local links are represented by direct single-modal (e.g., road, rail, power- or telecommunication line, etc.) connections between entities or their hubs (e.g., warehouses, bus/train stops, power banks, base stations), while regional/global links involve multi-modal (e.g., road, rail, ship, air, wired/wireless etc.) regional/global hubs (e.g., distribution centers, bus/train stations, distribution/relay stations).

The connections between entities are established by the domain services according to the small-world principle [37]. The grids are formed in the transport layer of the respective OSI model, while the routing and optimization are performed in the network layer. Here, also the pertaining protocols involving different types of iLSs with their roles are defined (e.g., the PhI, e-commerce; cp. [29]).

6.3. Domain service

Considering the domains of the underlying web services, different domain service categories may be defined in the same manner as the DNS service is defined for the Internet. The domain services should be run by local/regional/global hubs and structured hierarchically. Considering the current application areas, they should include, but should not be limited to, at least the following domain services (see Figure 4):

- e-commerce (.com) – the yellow pages service;
- PhI (.net) – the PhI service;
- CSN (.org, .edu and .gov) – the white pages services;
- MSN (.net) – the MSN service;

For obvious reasons, such a classification scheme shall make the domain services more flexible and easier to maintain. To support appropriate layering, the domain services should have the same structure for the local (city/region), regional (state/continent) and global domains (world), featuring internal and exterior gateway functions for their interconnection.

In addition, to enable cross-domain services, like the one mentioned in the introduction, the domain services should be integrated by the core domain network gateways (see Figure 6) in order to ensure cross-network and cross-domain interconnections, which are necessary to perform smart functions requiring services from different domains' networks.

6.4. Summary

Here, the foundation of the OIM of Society 5.0's infrastructure services has been described in its entirety. Existing application-specific standards regarding their quality, safety and security may be applied differently in distinct cases. However, when applied appropriately, they can be accounted for early in their life-cycle to ensure high-quality and sustainable operation.

As with the Internet, the main merit of successful implementation of Society 5.0 services will be their QoS. As a consequence, similar QoS indicators should be used to assess their performance, safety and security [2]. To ensure their sustainability, integrated logistics support (see ils in Figure 4) standards and guidelines [38] should be followed in their implementations to ensure proper life-cycle maintenance as well as the systematic introduction of the future generations of services and new services as they arise.

7. Conclusions

In the article, the infrastructure and services of Society 5.0 have been classified according to their areas of use. The associated interoperability models and mechanisms have been discussed in terms of defining appropriate digital twins, as well as their collaboration protocols and XR interfaces. The design guidelines for defining smart infrastructure services within the presented OIM of Society 5.0 have been elaborated. They are oriented at systems engineers and content managers to enable them to systematically consider all aspects of newly defined services. By doing so, eventually, following the concept of a modular platform, this shall allow for further integrations of novel smart services into related geographical and application areas.

To answer the question if this would make our society better and more resilient against catastrophes, one can make a positive conclusion. It should and it shall, provided that people will be more open for cooperation than competition. Any new service in Society 5.0 should be inspected for its safety before it is included in the ecosystem and allowed to grow and evolve. By the principles of evolution, services shall appear, grow and disappear depending on their use. Some regulation may be necessary to detect and prevent the spread of malicious services, however, mostly, they would be ruled out by the rest of the Society 5.0 services. As always, this is a question for the authorities, which should have the tools and means, but should act impartially.

8. Future works

In spite our efforts, the broader acceptance of integral smart city solutions has not yet persuaded decision-makers. Hence, the development and introduction of partial smart solutions continues. Standardization initiatives like the OLI model and MIMs have not yet received broader support by mainstream industries. Hence, a collaborative standardization effort like the OPC UA is still awaiting realization. An international advisory board on this may provide a solution to this problem. To be successful, however, it should be oriented globally and be internally consistent.

Thus, our goal is to connect with the aforementioned individuals and organizations as well as technology providers, to form a competent body of knowledge that can be used as a reference for companies and communities in the development and introduction of new solutions. It is only in this way that inclusive, interoperable and sustainable solutions will eventually be developed. Only then will they be able to provide AI support at higher levels of decision-making within the Society 5.0. Nevertheless, this research sets the foundation to enable this.

Use of AI tools declaration

The authors declare they have not used Artificial Intelligence (AI) tools in the creation of this article.

Conflict of interest

All authors declare no conflicts of interest in this paper.

References

1. N. Kalatzis, G. Routis, Y. Marinellis, M. Avgeris, I. Roussaki, S. Papavassiliou, et al., Semantic interoperability for IoT platforms in support of decision making: an experiment on early wildfire detection, *Sensors*, **19** (2019), 528.
2. R. Gumzej, *Intelligent Logistics Systems for Smart Cities and Communities*, Springer, 2021.
3. M. Avgeris, N. Kalatziset, D. Dechouniotis, I. Roussaki, S. Papavassiliou, Semantic resource management of federated IoT testbeds, in *Ad-hoc, Mobile, and Wireless Networks*, Springer, 2017. https://doi.org/10.1007/978-3-319-67910-5_3
4. F. Sabbatini, G. Ciatto, A. Omicini, Semantic Web-Based interoperability for intelligent agents with PSyKE, in *Explainable and Transparent AI and Multi-Agent Systems*, Springer, 2022. https://doi.org/10.1007/978-3-031-15565-9_8
5. B. Montreuil, E. Ballot, F. Fontane, An open logistics interconnection model for the physical internet, *IFAC Proc. Vol.*, **45** (2012), 327–332. https://doi.org/10.3182/20120523-3-RO-2023.00385
6. OASC, MIMs, Minimal Interoperability Mechanisms - MIMs, Open & Agile Smart Cities, 2022. Available from: https://oascities.org/minimal-interoperability-mechanisms/.
7. B. Salgues, *Society 5.0: Industry of the Future, Technologies, Methods and Tools*, John Wiley & Sons, 2018.
8. A. G. Kravets, A. A. Bolshakov, M. Shcherbakov, *Society 5.0: Human-centered society challenges and solutions*, Springer International Publishing, 2022.
9. M. M. Nair, A. K. Tyagi, N. Sreenath, The future with Industry 4.0 at the core of Society 5.0: Open issues, future opportunities and challenges, in *2021 International Conference on Computer Communication and Informatics (ICCCI)*, (2021), 1–7. https://doi.org/10.1109/ICCCI50826.2021.9402498
10. Y. B. Jiao, Based on the electronic commerce environment of intelligent logistics system construction, in *Advances in Applied Sciences and Manufacturing*, (2014), 1057–1060. https://doi.org/10.4028/www.scientific.net/AMR.850-851.1057
11. M. Kiba-Janiak, J. Marcinkowski, A. Jagoda, A. Skowrońska, Sustainable last mile delivery on e-commerce market in cities from the perspective of various stakeholders. literature review, *Sustainable Cities Soc.*, **71** (2021), 102984. https://doi.org/10.1016/j.scs.2021.102984
12. H. Quak, R. van Duin, B. Hendriks, Running an urban consolidation centre: Binnenstadservice 10 years back and forth, *Trans. Res. Procedia*, **46** (2020), 45–52. https://doi.org/10.1016/j.trpro.2020.03.162
13. S. Iwan, K. Kijewska, J. Lemke, Analysis of parcel lockerséfficiency as the last mile delivery solution-the results of the research in Poland, *Trans. Res. Procedia*, **12** (2016), 644–655. https://doi.org/10.1016/j.trpro.2016.02.018
14. E. Taniguchi, R. G. Thompson, *City Logistics 1: New Opportunities and Challenges*, John Wiley & Sons, 2018.

15. A. McKinnon, M. Browne, A. Whiteing, M. Piecyk, *Green Logistics: Improving the Environmental Sustainability of Logistics*, Kogan Page, 2015.

16. E. Taniguchi, R. G. Thompson, T. Yamada, New opportunities and challenges for city logistics, *Trans. Res. Procedia*, **12** (2016), 5–13. https://doi.org/10.1016/j.trpro.2016.02.004

17. N. Drop, D. Garlińska, Evaluation of intelligent transport systems used in urban agglomerations and intercity roads by professional truck drivers, *Sustainability*, **13** (2021), 2935. https://doi.org/10.3390/su13052935

18. S. Kauf, City logistics-a strategic element of sustainable urban development, *Trans. Res. Procedia*, **16** (2016), 158–164. https://doi.org/10.1016/j.trpro.2016.11.016

19. S. Guan, Smart e-commerce logistics construction model based on big data analytics, *J. Intell. Fuzzy Syst.*, **40** (2021), 3015–3023. https://doi.org/10.3233/JIFS-189340

20. P. Sun, L. Gu, Optimization of cross-border e-commerce logistics supervision system based on internet of things technology, *Complexity*, **2021** (2021), 11. https://doi.org/10.1155/2021/4582838

21. A. V. Barenji, W. Wang, Z. Li, D. A. Guerra-Zubiaga, Intelligent e-commerce logistics platform using hybrid agent based approach, *Trans. Res. Part E Logist. Trans. Rev.*, **126** (2019), 15–31. https://doi.org/10.1016/j.tre.2019.04.002

22. C. Pan, Construction of intelligent logistics model based on big data, *J. Phys. Conf. Ser.*, **1648** (2020), 022014. https://doi.org/10.1088/1742-6596/1648/2/022014

23. Z. Xu, J. He, Z. Chen, Design and actualization of iot-based intelligent logistics system, in *2012 IEEE International Conference on Industrial Engineering and Engineering Management*, (2012), 2245–2248. https://doi.org/10.1109/IEEM.2012.6838146

24. M. Zhang, S. Pratap, G. Q. Huang, Z. Zhao, Optimal collaborative transportation service trading in b2b e-commerce logistics, *Int. J. Prod. Res.*, **55** (2017), 5485–5501. https://doi.org/10.1080/00207543.2017.1322731

25. W. Liu, J. Zhang, S. Wei, D. Wang, Factors influencing organisational efficiency in a smart-logistics ecological chain under e-commerce platform leadership, *Int. J. Logist. Res. Appl.*, **24** (2021), 364–391. https://doi.org/10.1080/13675567.2020.1758643

26. W. Ying, S. Dayong, Multi-agent framework for third party logistics in e-commerce, *Expert Syst. Appl.*, **29** (2005), 431–436. https://doi.org/10.1016/j.eswa.2005.04.039

27. H. Zhang, Y. Liu, Q. Zhang, Y. Cui, S. Xu, A bayesian network model for the reliability control of fresh food e-commerce logistics systems, *Soft Comput.*, **24** (2020), 6499–6519. https://doi.org/10.1007/s00500-020-04666-5

28. Q. Zhou, Z. Zhang, Y. Wang, Research on safety management system optimization of b2c e-commerce intelligent logistics information system based on data cube, *J. Intell. Fuzzy Syst.*, **38** (2019), 1–8. https://doi.org/10.3233/JIFS-179522

29. R. Gumzej, Intelligent logistics systems in E-commerce and transportation, *Math. Biosci. Eng.*, **20** (2023), 2348–2363.

30. RF Wireless World, IoT Protocol Stack Layers–IoT Stack Layer 1 to Layer 7, 2012. Available from: https://www.rfwireless-world.com/IoT/IoT-Protocol-Stack-layers.html.

31. R. Gumzej, B. Rosi, Automated authentication and authorisation of consignors and their consignments within secure supply chains, *Tehnički Vjesn.*, **25** (2018), 203–209. https://doi.org/10.17559/TV-20160916124618

32. B. Posey, L. Rosencrance, S. Shea, Industrial Internet of Things (IIoT), 2022. Available from: https://www.techtarget.com/iotagenda/definition/Industrial-Internet-of-Things-IIoT.

33. B. Milić, B. Rosi, R. Gumzej, An approach to e-marketplace automation, *Tehnički Vjesn.*, **26** (2019), 639–649. https://doi.org/10.17559/TV-20171201150248

34. R. Gumzej, Safety and security beyond industry 4.0, *Int. J. Appl. Logist.*, **12** (2022), 1–10. https://doi.org/10.4018/IJAL.287556

35. S. Šinko, R. Gumzej, Towards smart traffic planning by traffic simulation on microscopic level, *Int. J. Appl. Logist.*, **11** (2021), 1–17.

36. D. Koss, *Zertifizierungsgerechter Entwurf betriebsmitteladäquater Automatisierungssysteme mit Sicherheitsverantwortung*, VDI Verlag, (2023). https://doi.org/10.51202/9783186279088

37. A. B. Downey, *Think Complexity*, Green Tea Press, 2016.

38. ASD/AIA, Sx000i-International guide for the use of the s-series integrated logistics support (ils) specifications, 2016. Available from: http://www.sx000i.org/.