2020 | 4th International VDI Conference
Smart Construction Equipment - White Paper

The Role of Construction Machinery on an Automated and Connected Construction Site

TECHNISCHE UNIVERSITÄT DRESDEN

Stiftungsprofessur für **Baumaschinen**

Authors

Prof. Dr.-Ing. Frank Will
Stiftungsprofessur für Baumaschinen
Technische Universität Dresden
Münchner Platz 3
01187 Dresden

Volker Waurich
Stiftungsprofessur für Baumaschinen
Technische Universität Dresden
Münchner Platz 3
01187 Dresden

OVERVIEW

This white paper outlines the role of construction machinery in a construction process that is driven by model based life cycle management and digital information flow. The authors illustrate the role of machine automation and emphasize the importance of integrated data flow. In order to provide a holistic view on the interaction of customers, machine OEMs and software providers, several quality criteria for potential data transfer architectures are presented. Finally, three existing data transfer architectures are depicted.

POTENTIALS OF DIGITALIZATION AND AUTOMATION OF CONSTRUCTION MACHINERY

The construction industry did not manage to increase its productivity to the same degree as demonstrated by industrial manufacturing. Since the construction industry is characterized by a high level of manual labour, collaboration of various crafts and unique projects in heterogeneous environments, the preconditions for utilising automation and digitalization are comparatively poor. Whereas industrial manufacturing implemented a lean production policy for years, the construction business still struggles to establish lean processes. A big potential for improvement is an integrated and model based workflow that covers contracting, planning and the execution as well as approval and maintenance. Based on the mechanisms of Building Information Modeling, this is ongoing work. Although digital information flow across the whole product life cycle is far from being mature, it is worth clarifying the role of construction machinery in the digital construction process. Providing powerful interfaces and smart policies for data transfer is a key to keep up with future requirements of the digitalized construction industry.

THE ROLE OF AUTOMATION

Technical Advancements in the field of robotics, automotive, artificial intelligence and industry 4.0 are finding their way in the development of construction machines. Assistance systems, which support machine operation and process control, have been available for many years. Weighing systems, compaction control, and 2D/3D machine control for earth moving machinery for example have been adopted extensively. Similar to industrial manufacturing, automation seems to be the next step in order to accelerate productivity. In contrast to the five levels of automated driving by SAE J3016, the authors propose a construction machine specific definition in order to classify the terms assistance, automation and autonomy:

Assistance	Automation	Autonomy
Assistance systems support machine operation and process control but do not interfere in the control of the overall machine movement or operation	This refers to the automatic execution of sub tasks during machine operation. The automation system deals with sensing, processing and actuating of the sub process while the operator monitors the process and is able to steer the automated process.	Autonomy involves a complete machine operation under all conditions including decision making whether to put the machine in a safe state or not. Continuous human monitoring is not necessary in this case.

Figure 1 Characterisation of assistance, automation and autonomy

Various examples of automated construction machines have been developed both in industry and academia [1, 2, 3]. The development of automated construction machines aimed at increasing accuracy or productivity of machines compared to a human operator. In some edge cases, it might even pay off to operate fully automated vehicles if labour costs are high and the automation task is well manageable, e.g. autonomous hauling in an open pit. Most of today's construction sites are characterised by heterogeneous operating conditions and no special exclusion of pedestrians. Although there is a potential of enhancing machines with assistance systems and partly automated functions to operate more efficiently, an overall exploitation of these technologies might not be economic. A systematic approach would be not only to improve the construction machine itself but also to help unleashing the potential of the construction industry by enabling digitized and model based workflows. Digitalization is an ongoing process and it is important to exploit its potentials to optimize and interconnect planning, production and maintenance. According to a report by Roland Berger, the four keys to the digital transformation in the construction industry are digital data, automation, connectivity and digital access [4]. Automation of machine operation is already a well-covered field of development but the mechanisms of data flow across a machine should be questioned as well.

USE-CASES FOR CONNECTED CONSTRUCTION MACHINES

Digital interfaces for construction machines enable an extensive set of use-cases (see also ISO 15143-1 and ISO 15143-2). Most of these use-cases require a wireless connection between the machine and the receiving instance that can be another machine, a local site-management, a remote workplace or a public access point that connects the machine to the internet. It is not mandatory, that the machine data have to be accessible from the internet. Besides the enterprise-wide collection of fleet data, there are also rationales to keep the data on site in a custom network with lower delays and more flexibility in design. This applies especially for large construction companies. The following figure shows some use-cases for a data interface in relation to its requirements on throughput and latency.

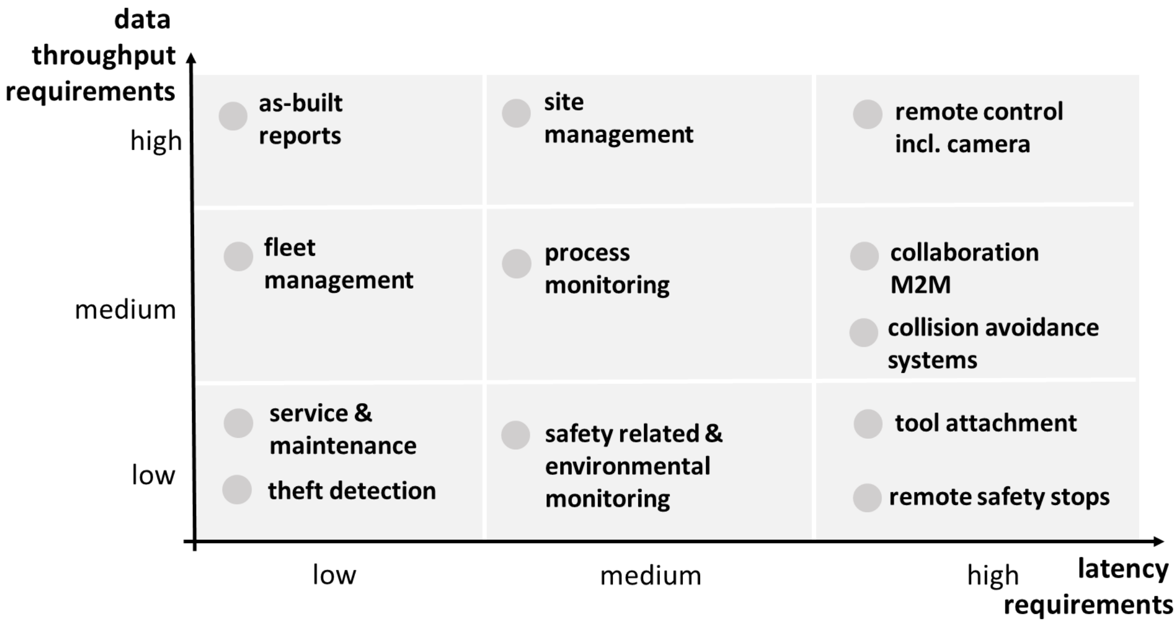

Figure 2 Throughput and latency requirements of different use-cases for a construction machine interface. High latency requirements refer to low delays e.g. hard real-time.

The most common use-cases for vehicle telemetry are fleet-management, service and maintenance notifications and theft detection. These applications have little demands on throughput and latency. To fit into model-based workflows, the machine has to process tasks and models from the site management and compile reports of the as-built state. As design models can be quite big, this requires a certain amount of throughput but without strict timing restrictions. Besides management purposes, the transfer of process data like loaded mass or asphalt temperature as well as safety related and environmental data like noise emission or monitoring of hazardous substances is bound to certain communication intervals but without hard-real-time criteria. The most demanding use-cases involve interference with the machines control system as e.g. remote safety stops, tool-control, collision avoidance systems and remote operation. Especially video streams or 3D-distances sensor data have extensive requirements on the data throughput.

THE CONNECTED CONSTRUCTION SITE BASED ON CURRENT STANDARDS

Several stakeholders benefit from the machine's ability to transfer data wirelessly and the goal should be to incorporate them all by a uniform and efficient system architecture. The machine manufacturer wants to sell the machine's data to the customer but also wants to reuse the operating records for internal evaluation. The contractor needs machine records for the management of logistics, cost and progress as well as for maintenance planning and safety control. Surveying equipment that is an integral part of the machine delivers records for supervision, quality and progress control. Providers of fleet and site management software rely on accessible, comprehensive and powerful interfaces to deal with mixed fleets from several subcontractors. Suppliers of attachment and tools as well as system integrators that implement assistance and automation systems, require open, uniform and interoperable interfaces to develop scalable solutions.

The sole standard that describes a worksite data exchange procedure in the field of construction machinery is the ISO 15143-1 from 2010. It describes the data flow between contractor, the site information system and machine respectively measuring equipment, as depicted in the following figure.

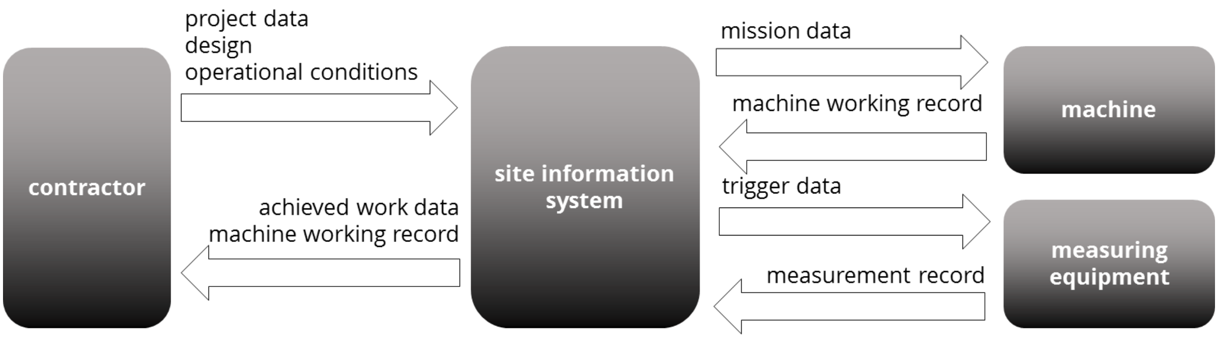

Figure 3 Architecture of a site information system according to ISO 15143-1

ISO 15143-1 covers the function of the participants, the data dictionary and the potential services related to the exchanged data. Neither a precise communication standard nor a communication protocol is prescribed. The second part of that series, ISO 15143-2 comprises an extensive set of data entities that can be applied, amongst others for project, design and machine management data as well as mission data for machines and measurement records. ISO 15143-3 specifies data items for telematics data and recommends in contrast to the other parts of this series the use of XML-Files that can be accessed via HTTPS-GET requests from a dedicated URL from the OEM-based dataspace. The third part contains the schema for describing around 20 basic data elements for telematics data. Currently, ISO 15143-3 is the only standard to implement manufacturer independent fleet management. The standard prescribes an OEM-server as the data source for data transfer to third-party applications.

ARCHITECTURE OF DATA TRANSFER

Before talking about radio technologies, data formats, interface standards and data dictionaries, one has to ensure that the data flow architecture itself provides the best conditions for all stakeholders. The next figure shows some basic system quality attributes that should be considered when designing a system architecture of connected construction machines.

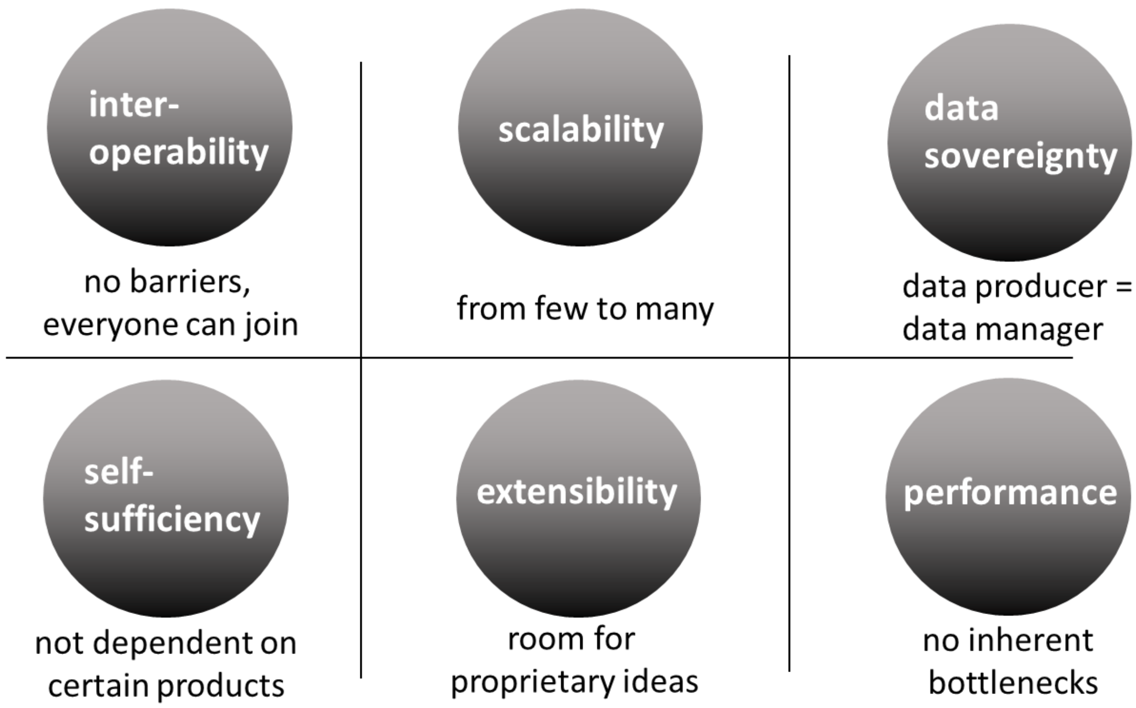

Figure 4 Quality attributes for the architecture of data transfer across construction sites

Interoperability is major issue, as contractors have to manage different subcontractors with mixed fleets using different software products. Scalability refers to the ability to cope both with the comprehensive control of a single machine and the management of thousands of assets. Data sovereignty addresses the right and possibility of all data owners to access, protect and transfer the data at their responsibility. In order to keep the ecosystem flexible and to avoid dependencies from technologies, vendors or regulatory restrictions, self-sufficiency is a basic requirement. Although one has to agree on certain standards, the architecture should promote extensions of the state of the art by proprietary innovative ideas without sacrificing compatibility. Finally yet importantly, the architecture should not incorporate inherent performance barriers to facilitate future application scenarios.

The following paragraphs describe three existing approaches to implement a data transfer incorporating machines, telematic-hardware suppliers, data spaces, software providers for fleet and site management and finally the user, i.e. the contractor.

THE PROPRIETARY DATA SPACE APPROACH

The proprietary dataspace approach reflects the current situation in construction machinery telematics. The sole standardised interface is the dataflow from the OEM-cloud-based dataspace to the fleet management software, currently defined by ISO 15143-3. The OEM of the construction machine is responsible for the telematic hardware on the machine, the information transfer from the machine to its endpoint of choice. The OEM telematics device presets the transmission technology. The data is then processed and stored on the OEM dataspace that provides the ISO 15143-3 interface accessible from the internet. Site and fleet-management software can access this data but have to negotiate access conditions with each OEM individually. The OEM accounts for the process and information control. This approach does not allow a local implementation of a site information system with alternative telematics hardware, transmission technologies or quality of service characteristics. As most OEMs offer their own fleet management solution, which fits their needs perfectly but is rather restrictive about including different manufacturers, the architecture is hardly extendable. The user (i.e. contractor) is confronted with many OEM-specific solutions and few third-party applications with limited capabilities.

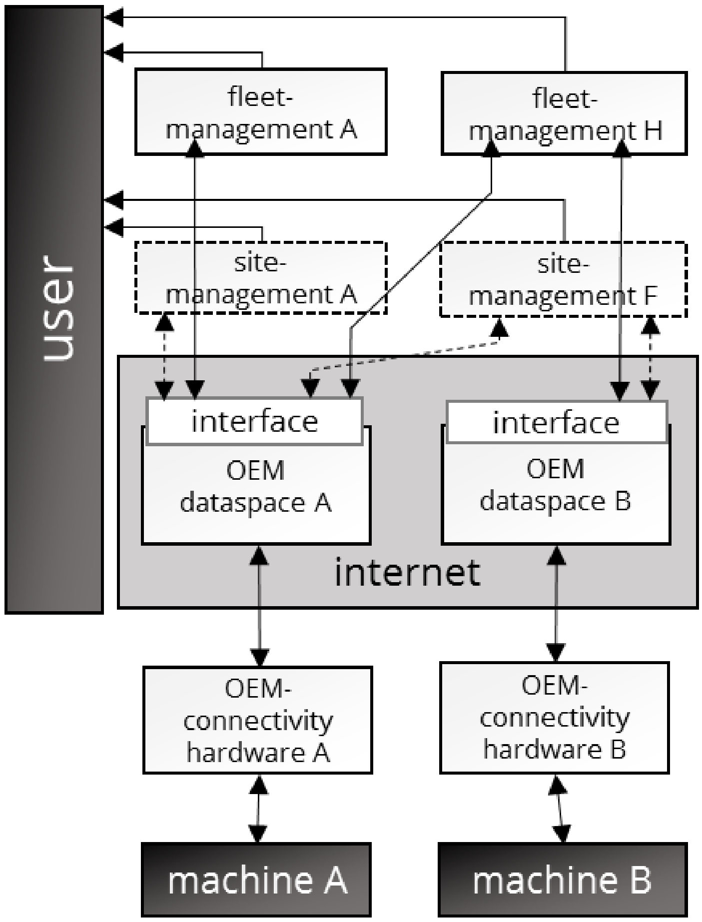

Figure 5 Schema of the proprietary data space approach

THE COMMON DATA SPACE APPROACH

This approach is based on the current need to manage the data flow between various stakeholders in an Industry 4.0 scenario. The main purpose of this approach is to establish a “Network of Trusted Data” that ensures data sovereignty of the data owner. A specific application is provided with the “International Data Space”, formerly known as “Industrial Data Space” [1]. The main aspect besides data sovereignty and security is the establishment of a decentralised, federal architecture with common policies that cultivates a vast ecosystem of platform and service providers that have access to data sources and data consumers. An illustrative example is the implementation of the “DKE Agrirouter” for connecting agricultural machines with farm management systems, which was rewarded as a positive example for business2business data sharing models [2, 3]. The common data space is a third party instance that captures and distributes data. This data space offers an open API for data input and data access, leading to a wide portfolio of third party vendors for telematics-hardware and farm management software. The data space ensures interoperability. Every manufacturer can supply its data that can be processed by independent management software. The only authority that is able to control the access rights of data is the user himself. The user decides which of his machines sends or retrieves data and which management system is allowed to consume the data and passes information back to the machine. Besides that, agricultural machines implement the ISO 11783 (ISOBUS) which is a manufacturer independent CAN-protocol. This allows third party telematics providers to interface the machines. This approach is ideal for small and medium customers who need capable management systems that offer flexibility and interoperability. When it comes to developing custom solutions for big companies that have special requirements on performance or want to have the perfect control on their data transfer, this approach has its limitations because the whole system is depends on the data space provider.

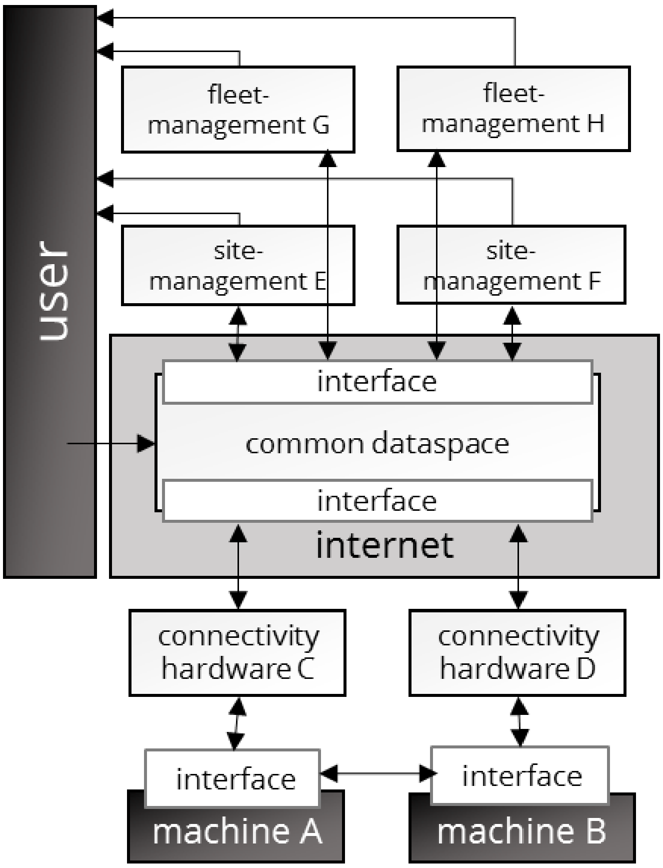

Figure 6 Schema of the common data space approach

THE MIDDLEWARE APPROACH

The middleware concept is a building block to implement component-based architectures. The middleware is a communication layer that allows a common language amongst all participating components, whether these are machines, telematic units or management applications. Even communication between machines is possible. The middleware organizes the data transfer between participants in a network and ensures safe and secure transactions. If the construction machine implements the middleware interface, any telematic unit is able to route the interface to a desired client. This would allow the interchangeable composition of all relevant components. Even a setup in a local network with mixed fleets and custom telematic hardware would be possible. This is especially interesting for large companies that favour an in-house solution for the site or fleet management. Nevertheless, a participation in a third-party data space is also feasible. A promising middleware technology for the connection of heterogeneous production systems is OPC-UA. OPC-UA is nominated to be the preferable solution for data access and information provision in the production and usage phase and fits in the reference architecture model RAMI 4.0 perfectly [2]. In Köhler et al. [3], a prototype of an OPC-UA data model for construction machines is presented. It is stated, that an OPC-UA server on a construction machine can be used both for fleet management and for 3D machine control with interchangeable telematic-hardware and client software.

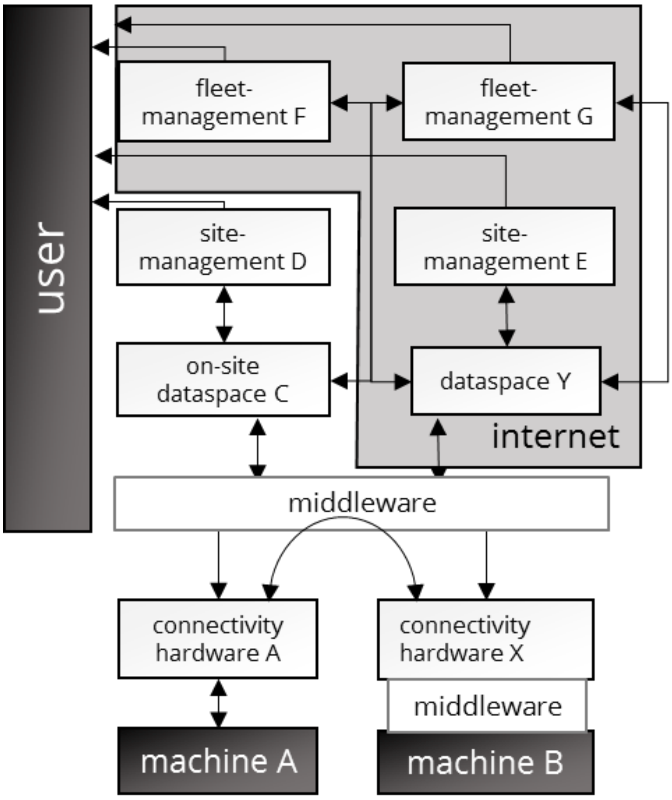

Figure 7 Schema for the middleware approach

COMPARISON OF DATA SHARING ARCHITECTURES

The following table gives an overview of the discussed architectures and their abilities to fulfil the requirements on data sharing on a construction site.

Table 1 Comparison of data sharing architectures with pros ("+") and cons ("-")

	proprietary data space approach	**common data space approach**	**middleware approach**
inter-operability	- hardly open for other hardware or software providers	+ based on open standards, all data is available by one interface	+ based on open standards and common data models
scalability	- interface each dataspace individually	+ only one interface per participant necessary	+ only one interface per participant - data aggregation effort
data sovereignty	- data access is controlled by the OEM data-space	+ user manages data rights	+/- data right management is implemented by the participant
self-sufficiency	- vendor-lock in	+ open for any telematics hardware and management software - dependent on data space provider	+ technology agnostic except for the middleware standard
extensibility	- dependent on OEM and standardization	+ no restrictions for additional data models, hardware solutions, software concepts	+ fully flexible approach
performance	- dependent on OEM, internet only	- dependent on data space provider, internet only	+/- limitations of the middleware-implementation

CONCLUSION

Construction machines can help to increase productivity in construction by leveraging the information flow amongst all stakeholders. This requires an efficient data transfer architecture as well as open standards that promote business-2-business data sharing. This white paper emphasizes the necessity to develop a comprehensive strategy for data exchange in the construction sector.

References

[1] D. Jud, P. Leemann und S. Kerscher, „Autonomous Free-Form Trenching using a Walking Excavator," *IEEE Robotics and Automation Letters,* pp. 3208-3215, 10 2019.

[2] Volvo Construction Equipment, „Volvo CE unveils the next generation of its electric load carrier concept," 03 09 2017. [Online]. Available: https://www.volvoce.com/global/en/news-and-events/press-releases/2017/conexpo-vegas-2017/volvo-ce-unveils-the-next-generation-of-its-electric-load-carrier-concept/. [Zugriff am 28 09 2020].

[3] Zeppelin Baumaschinen GmbH, „AutoDig: einmal einstellen - immer die optimale Füllmenge," [Online]. Available: https://www.zeppelin-cat.de/produkte/cat-lader/autodig.html. [Zugriff am 28 09 2020].

[4] K.-S. Schober und P. Hoff, „Digitization in the construction industry - Building Europe's road to "Construction 4.0"," ROLAND BERGER GMBHCivil Economics, Energy & Infrastructure Competence Cente, Munich, 2016.

[5] B. Otto, „Industrial Data Space - Digitale Souveränität über Daten," Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., München, 2016.

[6] European Commission Directorate-General of Communications Networks Content & Technology, „Study on data sharing between companies in Europe," European Commission, Luxembourg, 2018.

[7] „agrirouter," DKE-Data GmbH & Co. KG, [Online]. Available: https://my-agrirouter.com/. [Zugriff am 27 09 2020].

[8] F. Pethig und et al., „Industrie 4.0 Kommunikation mit OPC UA - Leitfaden zur Einführung in den Mittelstand," VDMA Verlag GmbH, Frankfurt am Main, 2017.

[9] S. Köhler, V. Waurich, B. Beck, D. Ritz, J. Weber und F. Will, „Netzwerkschnittstellen für mobile Arbeitsmaschinen im Kontext der digitalisierten Baustelle," in *8. Fachtagung Baumaschinentechnik*, Dresden, 2020.