The Organisational Benefits of Edge Computing Architectures

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Abstract

The rise of Edge Computing creates opportunities for enterprises to adapt their architectures to realise the benefits of ultra-low latency and real-time processing and performance. This paper explores the literary background of edge computing technology-based architecture and its associated technical benefits. The importance of business strategy and goal alignment with IS/IT enterprise architecture is acknowledged via EA methodology guidance and a practical gap is identified: a limited translation of edge-computing technical benefits into organisational benefits and how these can be employed for enterprise value realisation. Recent case studies of existing edge-involved enterprise architectures are investigated to translate technical benefits into organisational benefits, and explore how the technology has been and can be practically integrated into EA for value determination. The report introduces a value realisation model that proposes a three-step model for organisation value realisation. This includes the need for further research to determine if benefit translation can scale to a larger EA context, reference architecture resource collection for later use in edge-based EA development via EA methodologies, with TOGAF®[1] 9.2 recommended.

1. Background

1.1: Edge Computing and Architecture

Edge computing is a new computing paradigm that serves as an extension of cloud computing, bringing services closer to the periphery or 'edge' of the network. By doing so, an edge architecture can be established, consisting of a distributed network of heterogeneous devices, referred to as objects in the *Internet of Things (IoT)*, communicating with the larger network to perform processing, storage and other computing-related tasks as necessary.

Although it was originally developed for bandwidth reduction, edge-based architectures have demonstrated capacity to enable faster response times from enterprise applications and thus more rapid processing. Furthermore, the technology has proven its capability to combat high latency in applications and services that are delay sensitive in their delivery, and thus cannot be effectively handled by cloud architecture (Khan, et. al., 2019).

1.2: Edge Architecture: Technical Benefits

A multitude of technical benefits have arisen as a result of distributed data processing and analysis taking place at the network periphery, the source of the data itself, rather than between cloud servers. A major technical benefit is the highly reliable, ultra-low latency, high bandwidth, and real-time data accessibility and processing capabilities of the computing paradigm. As a result, organisations' systems are faster, with more rapid response times (Al-Ansi, et. al., 2021). Furthermore, the proximity of users to the site of

[1] TOGAF is a registered trademark of The Open Group.

information processing relieves the load on the cloud server, delivering greater quality-of-service (QoS) (Zhang, Cao & Dong, 2020).

From an organisational perspective, edge computing carries the technical capability to deliver effective big data analytics via collection of data from mobile devices and processing at smart gateways or indirectly via sink nodes in large-scale architectures (Khan, et. al., 2019).

The technology also enables mobility by decoupling host and location identifications, permitting direct communication with mobile devices on the network. Additionally, the technology is location-aware, and therefore able to facilitate proximity detection for mobile users or devices on the network, allowing devices to determine their closest edge server. This creates a foundation for reliable service.

1.3: The Gap Between Technological and Organisational Benefits

Despite the plethora of technical benefits created by the new edge computing paradigm, its integration into enterprise architecture (EA) requires purposeful EA management for effective organisational transformation. Thus, thorough consideration of how technological benefits can translate to organisational benefits is critical for business-IT alignment and maximum value realisation of enterprise investment in new architecture. EA architecture development methodologies involve recognition of critical business goals and suggest IS/IT alignment with them to create and realise organisation value.

The *Zachman Framework for Enterprise Architecture (ZFEA)* encapsulates *Motivation* at various levels across an organisation within its taxonomy; a key component in identifying why architectural artefacts will benefit an organisation at various levels. This includes artefacts that translate technological benefits, to align with the larger business strategies and goals, with specific purposes defined. This helps guide enterprises to align their activities with their high-level goals and strategy for IT and extended departments cohesively, facilitating maximal value realisation from their information system (IS) architecture investments (Nogueira, et. al., 2013).

TOGAF® incorporates Business Architecture in Phase B of its *Architecture Development Model (ADM)*, in which a gap is identified between current and target business architecture to design and build appropriate business and Technology Architecture, emphasising the need to establish IT/IS architecture that aligns with business strategy to create deliberate and meaningful value for the enterprise and its customers or clientele (Riwanto & Andry, 2019).

The literature surrounding enterprise architectures involving edge technology heavily demonstrates benefits from a technological perspective. However, there is little emphasis on how this technology can be incorporated into enterprise architecture development to translate these technical improvements into organisational benefits. Hence, EA methodologies would suggest that value proposition may not be realised if business-IT alignment is missing. Consequently, there is a practical gap established, bringing rise to the research question:

How can Enterprises Employ Edge Computing Architectures for Organisational Benefit?

2. Findings

2.1: Case Analyses of Existing Edge-Based Applications

In order to assess the benefits of edge computing integrations into enterprise architectures, contextual analysis is undertaken in the form of two distinct case studies, exploring how the technology benefits the organisation both technologically and from a business lens, whilst also introducing an architectural structure for practical employment.

2.2: Edge-based ERP System

The first case sees Prakash, et. al, (2022) explore the organisational benefits of applying an Edge Enterprise Resource Planning (E-ERP) system in the Industrial Internet of Things (IIoT) within the domain of a Smart Factory. Cloud and edge ERPs are investigated, demonstrating a plethora of technical benefits that are translated into larger organisational benefits that can, in the long term, provide enterprises with "substantial competitive advantage" (Prakash, et al., 2022). Figure 1 illustrates the ERP service model architecture, inclusive of E-ERP modules, serving as extensions of the cloud ERP server.

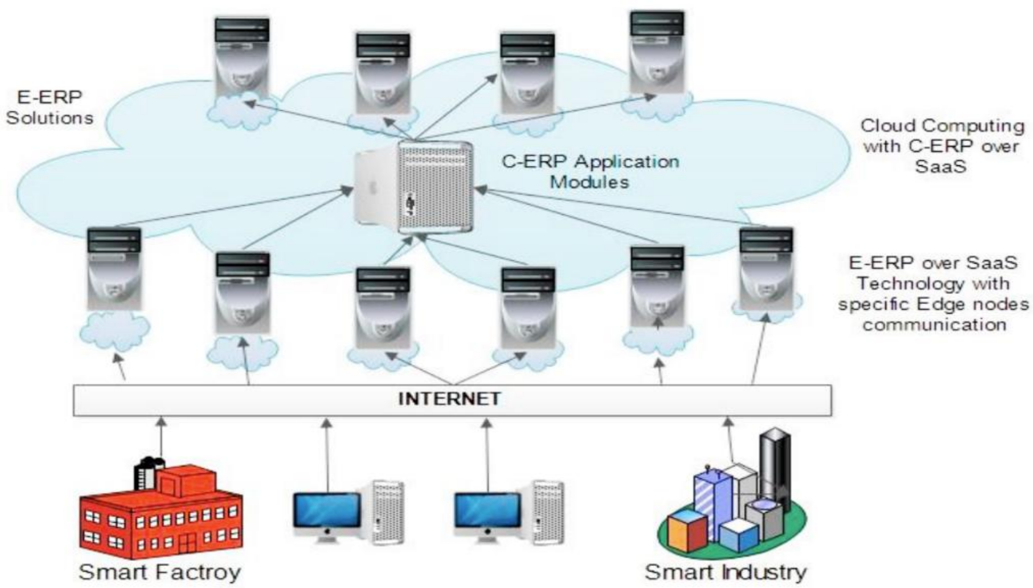


Figure 1: The ERP service model architecture, inclusive of E-ERP modules, serving as extensions of the cloud ERP server.

Whilst ERP systems do not reflect EA entirely, ERPs lie in the realm of a higher-level EA context (Eseryel & Wolff, 2005), and thus this analysis makes the assumption that the benefits are scalable to the larger context.

The organisational benefits of an ERP system are presented in the context of a Smart Factories and the IIoT, comparing modern cloud and edge technology to highlight the differences in processing at the periphery of the network rather than at a remote server. The ERP systems are established to provide operators and administrators with a comprehensive view of events and processes occurring in all areas of the factory. Building ERPs is a complex, expensive, and risky investment, and can have an impact on core business and support processes, especially in areas that involve cyber-physical systems. Applications for smart factories and IIoT are required to be able to share data in real-time and provide flexible responses to consumer behaviour in order to meet organisational needs. The application of the EERP in this case, specifically enables this real-time monitoring of production activities, helping to identify potential problems whilst simultaneously preventing downtime, leading to a more efficient supply chain management system.

From a technical perspective, as edge computing becomes more mature, it increasingly provides options for organisations. In this case, edge computing is able to provide ERP systems with greater flexibility to push computing resources and data processing power closer to the data source, proving useful for large factories in the industrial sector, where significant amounts of data need to be rapidly processed. In this context, where real-time data processing and analysis is necessary to improve supply chain management for competitive advantage, edge computing facilitates rapid response times in data generation, reducing data transfer times and latency, allowing instantaneous computational task completion.

In addition to processing data at a closer proximity, Prakash, et al., (2020) highlight that edge technology enables security elements to be brought closer to the source of attacks, enabling better security application performance. By moving computing resources to the edge, organisations gain the ability to operate autonomously while taking advantage of public and private clouds to perform complex computing processes more efficiently. Prakash, et al., (2020) then discuss how these technical benefits translate to organisational benefits as shown at Table 1.

Table 1: Technical Benefit Translation to Organisational Benefits

Flexibility and Agility	Increased agility and flexibility is a key organisational benefit that arises from edge computing integration into enterprise architecture, in the form of an ERP as presented in this case. This is the result of computational task completion at a more rapid and real-time rate than cloud computing alone, enabling businesses to adapt more swiftly to changing markets, giving organisations a significant competitive advantage.
Scalability	Another enterprise-level benefit, significant for long term growth, is the enhanced scalability offered due to the capability of E-ERP application modules to readily increase into new locations as required, enabling organisations to make better use of their resources and simplify maintenance, removing the need to maintain IT infrastructure.
Cost Savings	From a financial perspective, companies benefit mostly from cost reductions and an improved public financial image. The authors infer that large organisations enthusiastically adopt the cloud and E-ERP hybrid model due to its ability to deliver cost savings via lower initial spending, reduced operating costs and transparent total ownership costs. It is shown to be financially suitable for small and medium-sized enterprises due to its high data protection requirements, countering the need to expend on costly mission-critical systems. Thus, fulfilling the need for business continuity with low capital requirements.
New Business Models	E-ERP provides new information that can drive company plans towards a more customer-focused approach and new business opportunities.
Increased Business Productivity and Efficiency	E-ERP enables service, process, and procedure automation, increasing productivity for IIoT. These systems integrations also allow for data standardisation and interoperability, improving enterprise planning. By sharing workloads with edge nodes at the main ERP application server, the E-ERP model especially speeds up reporting and decision-making.

2.3: Edge Computing-based IIoT EA

The second case is analysed for investigation into a suggested practical Edge-based EA, serving as both a guide and a reference framework for developing EAs specifically tailored for the IIoT. This architecture is designed to seamlessly integrate E-ERP systems into IIoT and smart factory environments, addressing the unique challenges and requirements of modern industrial operations (Qiu, et al. 2020).

This case also occurs in the domain of a smart factory, to comprehensively demonstrate how this multi-layered, Edge Computing-based EA can add value to organisations. Figure 2. illustrates a practically structured edge-based EA for the IIoT, involving a multitude of layers.

By delving into the intricate layers of this advanced EA, spanning from the device and edge layers to the cloud application layer, this study elucidates how such a framework facilitates technical benefits such as enhanced data processing, real-time analytics, and organisational benefits including enhanced decision-making capabilities at various levels of operation. Prior to benefit discussion, a simplistic review of the case is explored via layer comprehension in Table 2.

This layered structure can serve as a form of reference architecture for EA development when integrating edge computing for organisational transformation (Qiu, et al. 2020). The case presents both technical and business benefits that arise from the various layers of the architecture. These include:

- **Real-Time Data Collection and Processing from Devices**
  In the context of the smart factory, various devices such as robots, conveyors, and sensors continuously collect data from the production line, including temperature, pressure, and speed. This data is transmitted in real-time to the edge layer for monitoring equipment status and production processes, ensuring devices operate at optimal conditions.
- **Rapid Response and Production Safety**
  In the Far-Edge Layer, Edge Controllers quickly identify and respond to potential equipment failures or production anomalies. For instance, if a machine's temperature exceeds the threshold or a worker's arm is caught in the machinery, the Far-Edge Layer can rapidly manage these crises with millisecond-level response times, ensuring production and worker safety and helping reduce production downtime and enhancing the reliability of the production line.
- **Data Processing and Quality Control**
  In the smart factory's Mid-Edge Layer, edge gateways directly connected to the production line's machines or robot control units collect critical operational data, perform data standardisation and storage, allowing upper-level systems to effectively interpret and utilise the data. Local computations reduce the need for data transfer to the cloud, decreasing latency. Edge gateways also monitor and adjust machine data in real time for product quality control, improving factory efficiency and productivity.
- **Efficient Strategy Formulation and Resource Optimisation**
  The Near-Edge Layer's long-term data trend analysis and complex decision support help management formulate more efficient production strategies. The Cloud Application Layer optimises supply chain management based on global or regional market demands.

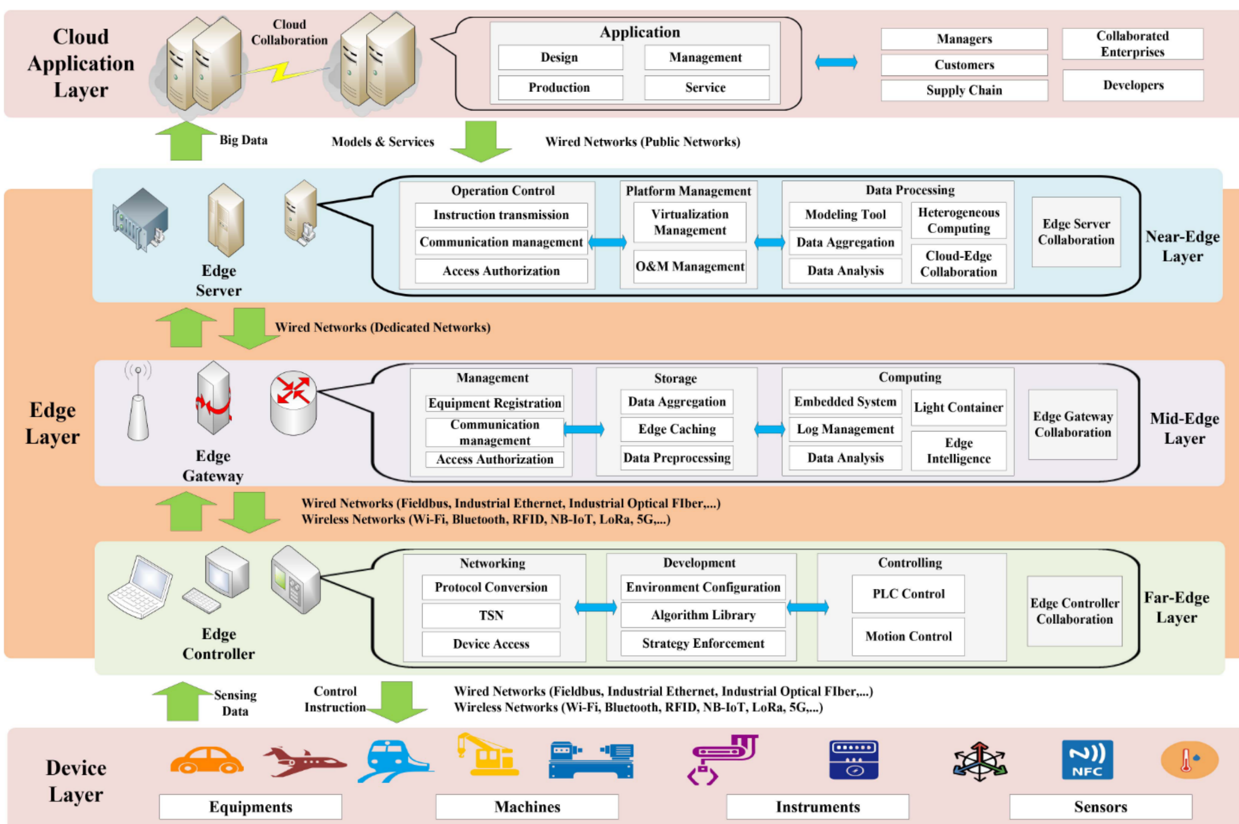


Figure 2: Edge-Computing Architecture in the IIoT (Qiu, et. al., 2020)

Through the analysis of E-ERP and smart factories, it is evident that this IIoT Edge Computing-based EA helps enterprises achieve comprehensive intelligence from the device layer to the corporate decision-making layer, reducing costs, enhancing efficiency and productivity, and supporting sustainable development.

Table 2. Example IIoT Edge Computing-Based EA Layer Descriptions

Device Layer	**Edge Layer**			**Cloud Layer**
	Far-Edge Layer	**Mid-Edge Layer**	**Near-Edge Layer**	
This layer includes varieties of machines, equipment, sensors, and instruments that collect a large amount of data and transmit it to the *Edge Layer* through wired or wireless networks, facilitating data flow between the device and edge layers.	The Far-Edge Layer includes edge controllers, primarily responsible for initial threshold judgments and data filtering. They have millisecond-level latency to respond quickly to emergencies and provide feedback.	This is the main data analysis layer. It processes, fuses, and caches data transmitted from the Far-Edge Layer, enabling multi-layer and multi-device collaboration for more comprehensive decision-making.	The Near-Edge Layer includes powerful edge servers that perform complex and critical data analysis to optimise processes or take optimal actions over a longer period, guiding decision-making.	This layer focuses on extracting potential value from massive amounts of data, enabling resource optimisation across companies, regions, and even nationwide.

3. Implementing Edge-based EA for Value Realisation

Following the above case analyses, it can be determined that the technical benefits of edge computing technology can be translated into larger enterprise benefits, and thus value can be realised by organisations following adequate integration into EA. The final component necessary for value realisation is the implementation of edge technology into EA during development and/or organisational transformation This requires appropriate EA Methodology selection and adaptation of the above suggested reference architecture.

3.1: Edge Computing Integration into Enterprise Architecture

With the growth of IoT, edge computing has become an integral part of EA owing to its technical benefits. However, without a well-defined EA methodology that outlines the initiation, transition, and governance of technologies, the technical benefits cannot be rolled out to enterprise-scale (Raj & Periasamy, 2011). Thus, in order for organisations to realise value from edge technology, appropriate EA methodology selection and implementation is required.

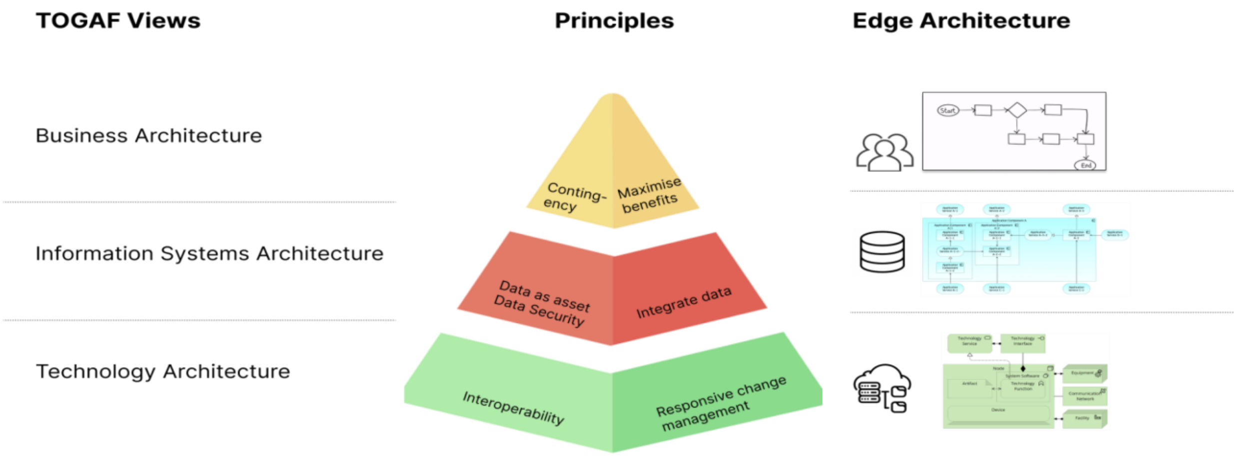


Figure 3.1.1. TOGAF® EA and Edge Computing (Created for this research, 2024)

TOGAF® is the most prominent EA methodology used by diverse types of organisations (The Open Group®, 2020). Due to actual EA practices adopted by companies, usually different from the original TOGAF® descriptions, EA and edge computing are presented based on the domain partitioning and architecture principles of TOGAF® 9.2.

Figure 3.1.1 illustrates the correlation between TOGAF® enterprise architecture and contemplated edge computing architecture, demonstrating how edge architecture can be integrated at each level to achieve the larger goal of maximising organisational benefits.

Business Architecture

This phase of the architecture development model (ADM) focuses on ensuring edge integration aligns with business goals. Business architecture defines actors, roles, and business processes. Specifically, business processes provide a picture of business operations, through which organisations can evaluate the effectiveness and efficiency of business processes to optimise decision-making activities (Qurratuaini, 2018). The integration of edge computing and EA must align with two business architecture principles: firstly, to improve business contingency, addressing vulnerabilities caused by data load and bandwidth limitations, and secondly, edge technology adoption into EA is expected to translate as organisational benefits, previously identified to gain and sustain competitive advantage.

Information Systems Architecture

Information systems architecture provides a blueprint for the interconnected applications and the data flows they host. Applications are closely related to business processes, with data serving as their backbone. The linkage ensures coherence between application provision and business processes.

Data and applications are essential components in realising the functionality of edge computing. Edge computing includes additional data sources from IoT and APIs. Subsequently, edge applications perform data aggregation and data processing tasks such as generating alerts near data sources (Mijuskovic et al., 2020). Data-as-assets, data integration, and data security are principles for the information systems architecture. Edge computing captures comprehensive data sources to inform decision-making processes. Moreover, timely data integration and data processing applications can support accurate and prompt decision-making. Data is the primary asset for enterprises in establishing competitive advantages and strengthening the importance of data security.

Technology Architecture

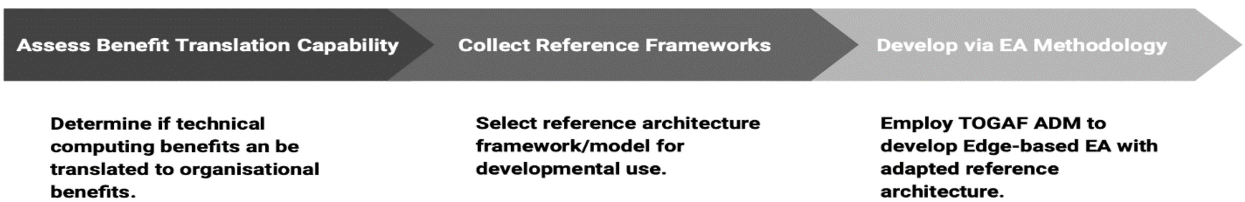
Technology architecture describes the logical and physical infrastructures that support applications in performing tasks, as explored in the previous case by Qiu, et al., (2020). It is critical in improving the quality of services for enterprises. The edge computing model couples layers of applications and converges with other enterprise services seamlessly. Interoperability with other systems and service-oriented architectures (SOAs) that are responsive to changes are guiding principles for constructing the technology architecture.

4. Discussion

4.1: Organisational Value Realisation Model for Edge-based EA Integration

Following the above analyses, a value realisation model is proposed for enterprises to determine how to employ edge computing architectures for organisational benefit, as per the research question. This is presented in Fig 4.1.1; it is a three-step process requiring direct translation of technical benefits to organisational benefits at an EA level rather than an ERP level, and collection of resources, such as Qiu, et. al. (2020)'s reference architecture for use in EA integration via EA methodology. In this study, TOGAF®, the methodology suggested, guides this process.

Figure 4.1.1. Organisational Value Realisation Model for Edge-based EA Integration



The model's first stage aligns with the E-ERP case study's findings that technical benefits can be translated to organisational benefits, but proposes future investigation into whether this is scalable from ERPs to EA. The second stage involves collection of reference architectures for use by enterprises later in their own organisational employment of edge computing. Finally, the third stage involves EA methodology, in this case, TOGAF®, to guide edge-based EA development and implementation for individual organisational benefit realisation.

4.2: Implementation Considerations

Some key considerations to take into account when determining whether to proceed with the architecture are:

Implementation Risks

Although edge computing has been undergoing continuous research and improvement in academic and industrial systems, it still faces several unresolved challenges, including performance enhancement, privacy enhancement, resource management, benchmarking, and integration of software-defined networking and network function virtualisation (Carvalho et al., 2021; Pan & McElhannon, 2018; Chen & Ran, 2019). These technologies are not yet mature, and related research is still at an early stage. Notably, in a highly heterogeneous edge network, different devices and applications have their security requirements. At the same time, the transmission of sensitive data and the physical proximity of edge cloud servers to users significantly increase the risk to privacy and physical security.

To mitigate these risks, organisations need to innovate and adapt at a technical and strategic level to address the challenges of edge computing. It will be crucial to develop dedicated security protocols for edge computing or create more dynamic resource management tools that can speed up deployment and improve system operational efficiency. As technology evolves further, edge computing will face new technical challenges and present new opportunities for innovation.

Education and Skills Inadequacies

The rapid growth of edge computing requires a workforce with a number of skills, including advanced programming skills, an understanding of distributed systems, knowledge of data security and privacy protection, and the ability to design and implement low-latency communication solutions (Dec, et al., 2022).

However, existing university curricula remain inadequate to cover these required theories and practices, with only a few faculty members covering edge computing being insufficient for industry needs (Dec, et al., 2022). Rapid changes in this emerging field often render new curriculum content outdated by the time it is approved and updated, reducing its real-time applicability and usefulness for students. Furthermore, the educational process often fails to focus on how edge computing can be used to solve industrial problems. Key technical areas related to edge computing are often under-explored (Paśko, et al., 2022). Addressing these needs requires close collaboration between academia and industry, essential to prepare the workforce for future enterprise architectures. Such collaborations enable universities to utilise new infrastructures and integrate professional experiences whilst also offering more practical teaching methods.

5. Limitations

Due to the literature gap regarding the practical organisational benefits of integrating edge technology into EA, benefit translation has been undertaken via a case analysis looking purely at ERPs. Despite the assumption that this will scale to the larger EA space that ERPs lie within, it remains a limitation as it cannot be determined with certainty if this is transferable. Future research would benefit from practically integrating Edge-based module applications into EA and determining the actual benefit translation capacity.

Furthermore, a limitation of this study remains that a single industry context was explored via cases in the domain of smart factories. Thus, future research would benefit from exploring the benefits of EA outside of this industry and across varying industries.

6. Conclusion & Implications

Research conducted strongly insinuates that the technical benefits of edge computing presented in the literature can be translated to organisational benefits, but further research is required to determine if the pattern occurs at an EA level and outside of an industrial context. This is reflected in the value proposition model, with the first step assessing for actual benefit translatability, before moving on to reference architecture resource collection and edge-based EA development using EA methodologies.

The findings of this study allow a multitude of smart industries and organisations to anticipate innovation potential, demonstrating potential for benefit and value realisation from the integration of edge computing in EA.

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