BISE Student

https://bise-student.io

Master's Thesis

From Affordances to Business Value – How Can Organizations Use Fog Computing to Create Business Value?

Publication Date: 2023-10-23

Author
Yannick Erb
Karlsruhe, Germany
yannick.erb@kit.edu
0x6DCfeBF35d05d5906b6C3808F81C5ADAa9816aD6

Abstract

Fog computing (FC) is an uprising technology emerging to solve problems arising from the usage of cloud computing (CC) in handling the large volume of data created by an increasing amount of intelligent edge devices in a timely manner. However, there are still only a few real-world implementations of FC, and the discussion remains mainly in academia. Research currently falls short in guiding organizations in elaborating on FC usage for value creation, as it mainly neglects a discussion on this technologies business values. Therefore, this work set out to investigate how fog computing creates or enhances business values for an organization. By conducting a literature review comprising 58 publications and taking an affordance theoretical point of view in subsequent thematic analysis (TA), I derive 61 FC affordances (in four top-level themes), 12 service types (in three top-level themes), and 32 business values (in four top-level themes). Based thereon, eight business value creation sets (BVCSs) have been created, showcasing...

Keywords: Fog computing, FC, Business Value, Thematic Analysis
Methods: Literature Review, Thematic Analysis

Submission Date: 2023-10-23
Submission Contract: 0x0f126961fDb669e66BC2A9C0527e1aa6906a98C8

From Affordances to Business Value – How Can Organizations Use Fog Computing to Create Business Value?

Master Thesis

by

Yannick Erb

Degree Course: Information Systems
Matriculation Number: 2057038

Institute for Applied Informatics and Formal Description Methods (AIFB)
KIT Department of Economics and Management

Advisor:	Prof. Dr. Ali Sunyaev
Second Advisor:	Prof. Dr. Andreas Oberweis
Supervisor:	Dr. Sebastian Lins
Submitted:	31. July 2023

Abstract

Fog computing (FC) is an uprising technology emerging to solve problems arising from the usage of cloud computing (CC) in handling the large volume of data created by an increasing amount of intelligent edge devices in a timely manner. However, there are still only a few real-world implementations of FC, and the discussion remains mainly in academia. Research currently falls short in guiding organizations in elaborating on FC usage for value creation, as it mainly neglects a discussion on this technologies business values. Therefore, this work set out to investigate how fog computing creates or enhances business values for an organization.

By conducting a literature review comprising 58 publications and taking an affordance theoretical point of view in subsequent thematic analysis (TA), I derive 61 FC affordances (in four top-level themes), 12 service types (in three top-level themes), and 32 business values (in four top-level themes). Based thereon, eight business value creation sets (BVCSs) have been created, showcasing how affordances can aid services to achieve business values for organizations. To the best of my knowledge, this work is the first of its kind for identifying the potential value of FC, building a stepping stone for research and practice.

Table of Contents

List of Abbreviations

BVCS	Business Value Creation Set
CC	Cloud Computing
DOI	Digital Object Identifier
EC	Edge Computing
FC	Fog Computing
FN	Fog Node
FS	Fog System
IaaS	Infrastructure as a Service
ID	Identifier
IoT	Internet of Things
IS	Information System
MEC	Mobile Edge Computing
NIST	National Institute of Standards and Technology
PaaS	Platform as a Service
QoS	Quality of Service
RSU	Road Side Unit
SaaS	Software as a Service
TA	Thematic Analysis
VFC	Vehicular Fog Computing
WiFi	Wireless Fidelity

List of Figures

List of Tables

1. Introduction

Fog Computing (FC) is a novel computing model that bridges the geographical and logical distance between smart end devices and centralized cloud services by introducing a middle layer consisting of context-aware fog nodes (FNs) (Iorga et al., 2018, p. 2; Yousefpour et al., 2019, p. 4). This three-layered model tries to overcome problems that use cases needing real-time low-latency data processing and decision-making pose to cloud computing (CC) (Naha et al., 2018, pp. 47980–47981; Yousefpour et al., 2019, p. 1). While CC comes with the possibility for powerful computational and analytical capabilities and provides extensive storage capabilities, the geographic distance between CC data centers and the end devices in need of data processing or decision-making leads to higher latency (Yousefpour et al., 2019, p. 4). This is especially problematic since, for example, the number of connected devices on the Internet of Things (IoT) is rising (Vailshery, 2022). The introduction of FNs that are computing resources being location-sensitive and in geographic proximity of the end devices enables local preprocessing and filtering of the data sent by the end devices to ease load against the cloud service or provide storage capabilities to the devices connected (Yousefpour et al., 2019, p. 4).

Faced with the uprising of FC, organizations need to elaborate on whether adopting this novel technology provides any business value to them. Currently there are only few existing real-world implementations in productive use. One such example of a fog-like approach is the usage of Amazon Web Services IoT Greengrass by the Japanese company Yanmar for their greenhouse surveillance, plant growth monitoring, nutrition and water supply fine-tuning, via intelligent cameras, sensors and an edge computer for data (pre-)processing within their greenhouses (Vieru, 2018). But also research is interested in investigating the usage of FC in real world settings. Together with Navantia, a Spanish shipbuilder, researchers employ a FC cyber-physical system to monitor and track pipes in one of Navantia's pipe workshops to increase efficiency and productivity (Fraga-Lamas et al., 2020). But not only large companies may benefit from this novel computing paradigm. Accompanied by researchers, Mediterranean olive groves are equipped with sensors and FN for almost real-time monitoring of humidity, soil moisture, ultraviolet ray intensity, and temperature, which are critical for olive tree health and the quality of the final product (Tsipis et al., 2020). Like this, olive growers can react immediately by taking countermeasures and precautions, if necessary, to ensure the quality of products and the health of their groves.

However, the discussion on FC's usage scenarios remains mainly at a research level. Elaborating on FC usage research finds that, organizations may use FC as a substitution technology to use cases where CC is employed without achieving further benefits. FC and CC have the same commercial value even though it is suggested to conduct further research on FC value and the creation of a mature business model (Mai, 2019, p. 5). FC, however, is also reported to have the potential to change how value is created for organizations in these fields or even enable entirely new business cases. With, for example, the number of connected or even self-driving vehicles (Hou et al., 2016, p. 3860; Ning et al., 2019, p. 87) and IoT devices (Vailshery, 2022) rising, being able to cope with massive amounts of data while remaining low latency may emerge as a competitive factor for organizations in many contexts. Thus, organizations may use FC to achieve incremental improvements compared to the usage of CC or related technologies. For example, using FC instead of CC in space technology may lead to substantial improvements in the Quality of Service (QoS), especially in terms of delay (Cao et al., 2019, p. 168). Finally, FC may also enable entirely new use cases and business models impossible before. For example, new business ecosystems for smart ocean scenarios with various stakeholders such as shipping firms, fisheries, telecommunication, and global logistics are sketched (C. Zhu et al., 2022, p. 30). A collaboration of fisheries and network operators is envisioned for gathering and providing accurate spatiotemporal information about fish schools in a vast area, which may be provided to fisher boats in a location-aware manner for a certain utility period (C. Zhu et al., 2022, p. 29).

However, it remains unclear how organizations can use FC for their value creation and benefit from its capabilities. As FC remains in the domain of research and only a few real-world examples of FC are being used, practitioners seem to lack guidance on whether FC can help their organization and when to use this novel computing model.

Research on FC on the other hand has gained significant traction over recent years. The literature focusing on applying FC, proposes FC architectures for particular use cases (e.g., maritime applications (C. Zhu et al., 2022), or urban water distribution monitoring (Mirzaie et al., 2021)), facilitates their evaluation (e.g., Alghamdi et al. (2019), Knebel et al. (2021) and prototyping (e.g., Beri et al. (2022), Tsipis et al. (2020)). Synthesizing literature focuses on investigating FC characteristics and their interdependencies, for example Blume et al. (2022), on providing reference architectures (e.g., Dastjerdi and Buyya (2016)) or on investigating potential use cases (e.g., Yousefpour et al. (2019)). However, prior research mostly neglects to elaborate on the value businesses can achieve when adopting proposed FC systems. Only two studies could be identified touching that. Perifanis and Kitsios (2022) investigate the impacts of IoT solutions on organizations business value streams and include FC as a value driver for IoT. And Malic et al. (2020) identify and discuss factors for FC adoption by organizations. However, both fall short on answering how business value can be created by relying on FC, as they either evolve their research around IoT as a technology or stay mostly on a FC capabilities level without connecting these to organizations’ business values.

To enable organizations for a decision on whether to adopt FC for their business, research must move from discussing single use cases and research prototypes to a more adoption-driven perspective allowing to elaborate on when FC benefits organizations and can create or enhance their business value.

To initiate such a discussion and aid practitioners in their decision, I raise the following research question:

How can fog computing create or enhance business value for an organization?

Therefore, the main goal of this work is to answer how organizations can achieve business value by relying on the capabilities FC offers. A literature review is performed to reach this goal, and several sub-goals concerning different parts of the question must be achieved.

The first sub-goal is to identify FC`s capabilities. To do so, I employ an affordance theory point of view. Affordance theory and the concept of affordances has gained traction in information system (IS) literature to investigate the value of digital technology (Dremel et al., 2020, p. 2). An affordance is described as a potential for behaviors to achieve an outcome and arises from the relation between an IT artifact and a goal-oriented actor (Volkoff & Strong, 2018, p. 4). By using affordance theory, research can move from discussing FC capabilities independently to a more organization-focused discussion of what FC offers to these organizations. Affordance theory can be used as a lens to identify the affordances of an IT artifact or technology (Volkoff & Strong, 2018, p. 11). As affordances only arise from the relation of an artifact or technology and an actor (Volkoff & Strong, 2018, p. 4), it is necessary to distinguish between different actors (e.g., users of the system, organizations providing and operating a FC system, organizations providing, for example, vehicles that are part of the system, etc.) involved in a FC system to identify the affordances the system offers them. FC's affordances are identified and grouped into themes using thematic analysis (TA) (Braun & Clarke, 2006) to identify affordances and capture patterns and connections between the different affordances.

As a second sub-goal, the business values that can be achieved by using FC are identified. Again, the lens of affordance theory proves helpful. Affordances are associated with a concrete outcome the actors are trying to achieve (Volkoff & Strong, 2018, p. 4). For this work, these outcomes and the actors' goals are perceived as the business values they try to generate. The identified business values are grouped thematically.

Third, I investigate which affordances lead to which business values, using the themes identified beforehand. To do so, the affordance themes shall be linked to the business value themes by considering the relationship of affordance, actor, and goal as described by affordance theory. This shows how the potential FC comes with can be used in different scenarios to create or enhance business values.

The review comprises 58 articles from which 61 affordances grouped in four top-level themes and 32 business values in 4 top-level themes could be identified. Furthermore, 12 service types in three top-level themes are identified that can be built using FC affordances to achieve business values. I then collated eight business value creation sets (BVCSs) describing which business values are achieved by which services relying on which affordances.

By uncovering FC affordances and business values described in FC literature, I extend knowledge on the value FC provides to organizations and show how this can be achieved in form of eight BVCSs. Organizations can use those as guidance when elaborating on whether and how they can employ FC for their value creation.

I, furthermore, see my work as a basis for future work in the field of FC affordances and business values and provide opportunities for future research worth investigating.

The remainder of this work is structured as follows. Chapter 2 provides background information, introduces FC and the related concepts of CC and Edge Computing (EC), and contrasts them. Moreover, related research on FC, its capabilities and its business values is presented. Chapter 3 describes the methods used for data collection (section 3.1) and data analysis (section 3.2). The results of this work are presented in Chapter 4, followed by a discussion of principal findings, limitations, the impact of this work, and possible future research opportunities in Chapter 5. Chapter 6 briefly concludes this work with final remarks.

2. Background

2.1. Fog Computing

„Fog computing is a layered model for enabling ubiquitous access to a shared continuum of scalable computing resources“ (Iorga et al., 2018, p. 2). This model encompasses context-aware FNs that are placed between centralized cloud services and smart end devices (Iorga et al., 2018, p. 2), resulting in a three-layer architecture composed of a cloud layer, a fog layer, and the layer in which the edge devices reside. Such a generic architecture can be seen in Figure 1 and can be referred to as a fog system (FS) (Blume et al., 2022, p. 1).

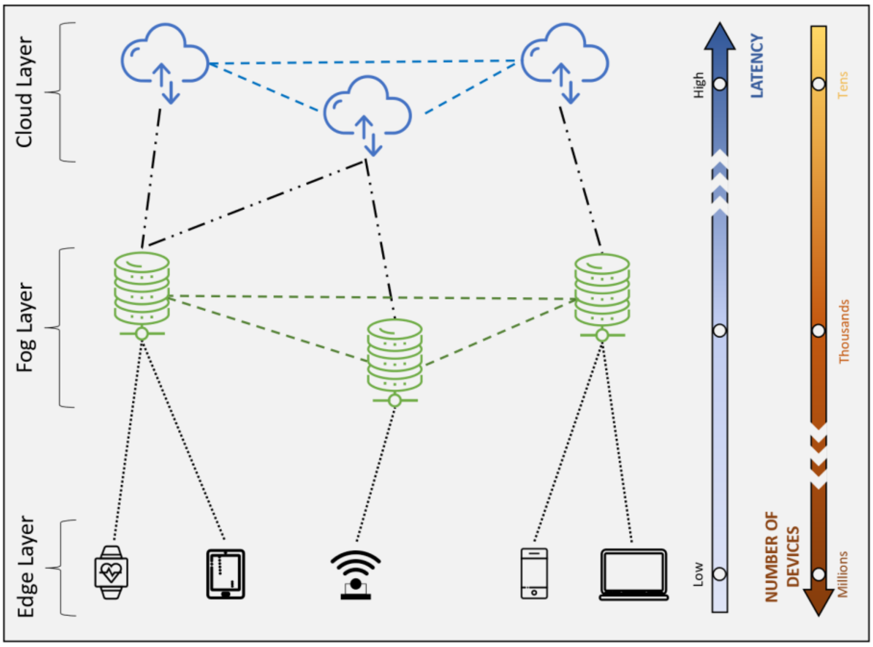


Figure 1: Generic three-layered FS architecture (adapted from Iorga et al. (2018, p. 2))

Providing computing resources to the end devices, as well as data management and communication services between end devices and the cloud layer, the heterogeneous FNs are the central components of the FC architecture (Iorga et al., 2018, pp. 3–4). Being context-aware, FNs know their geographic and logical location in the system. The strength of the capabilities FNs can provide are typically between the edge devices and connected cloud services (Muneeb et al., 2021, pp. 4–5). However, this may vary for different use cases, ranging from FNs being gateways in the role of a connectivity hub to FNs providing extensive capabilities as a mini data center (Blume et al., 2022, p. 128). Furthermore, FNs can operate autonomously, support hierarchical clustering, are inherently programmable, and can be managed by complex systems (Iorga et al., 2018, p. 4).

FC comes with several essential characteristics described by Iorga et al. (2018, pp. 3–4). These are summarized in Table 1.

Table 1: FC essential characteristics as described by Iorga et al. (2018, pp. 3–4)

Characteristic	**Description**
Contextual location awareness, and low latency	Fog computing offers the lowest-possible latency due to the fog nodes' awareness of their logical location in the context of the entire systems and of the latency costs for communicating with other nodes. […] Because fog nodes are often co-located with the smart end-devices, analysis and response to data generated by these devices is much quicker than from a centralized cloud service or data center.
Geographical distribution	In sharp contrast to the more centralized cloud, the services and applications targeted by the fog computing demand widely, but geographically-identifiable, distributed deployments.
Heterogeneity	Fog computing supports collection and processing of data of different form factors acquired through multiple types of network communication capabilities.
Interoperability and federation	Seamless support of certain services (real-time streaming services is a good example) requires the cooperation of different providers. Hence, fog computing components must be able to interoperate, and services must be federated across domains.
Real-time interactions	Fog computing applications involve real-time interactions rather than batch processing.
Scalability and agility of federated, fog-node clusters	Fog computing is adaptive in nature, at cluster or cluster-of-clusters level, supporting elastic compute, resource pooling, data-load changes, and network condition variations, to list a few of the supported adaptive functions.

As already mentioned in the introduction, research has identified several use cases for FC. One of the most prominent use cases is the idea of using FC in a smart city context (e.g., Perera et al. (2018)) or integrating it into (smart) vehicles (vehicular FC (VFC)), for example, for real-time traffic management (e.g., Ning et al. (2019)).

2.2. Related Concepts – Cloud and Edge Computing

Cloud Computing

According to the National Institute of Standards and Technology (NIST), CC "is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" (Mell & Grance, 2011, p. 2). CC aids in expanding computing, storage and networking capabilities by using virtualized resources located in data centers (Yousefpour et al., 2019, pp. 2–3).

In comparison to FC, CC offers higher availability at higher power consumption due to CC utilizing large data centers (Yousefpour et al., 2019, p. 4). However, CC and FC are compatible and can be used alongside each other in a FS, as depicted in Figure 1 above. Using both computing paradigms allows for even further enhanced data aggregation and storage capabilities by preprocessing, filtering, and aggregating data already at the level of the FNs while analytically more complex queries or data that shall be archived can be sent to the cloud.

Edge Computing

Edge computing (EC) provides small data centers close to the user, having storage and computing resources only one hop away from the end devices (Open Edge Computing Initiative, 2023). Like this storage and processing power of connected devices is enhanced (Yousefpour et al., 2019, p. 7).

EC and FC are often confused (Iorga et al., 2018, p. 7). However, there are key differences. For example, EC is often limited to mere computing capabilities, whereas FC also addresses storage, networking, and control and is not hierarchical but limited to only a few layers (OpenFog Consortium Architecture Working Group, 2017). Moreover, the OpenFog Consortium defines edge computing with the exclusion of a cloud layer, whereas FC is compatible with CC.

As this work is not the first to contrast FC to CC and EC, and this is not in focus of this work, Table 2 compares the three computing paradigms based on several characteristics combined from Habibi et al. (2020, p. 69111) and Yousefpour et al. (2019, pp. 297–298). Both offer extensive descriptions and comparison of all three computing paradigms (and more beyond)[1].

*Table 2: Comparison of computing paradigms adapted and combined from Habibi et al. (2020, p. 69111)⁺ and Yousefpour et al. (2019, pp. 297–298)**

Paradigm **Criteria**	**CC**	**EC**	**FC**
Latency⁺,*	(Relatively) High	Low	Low
Delayed-Jitter⁺	High	Low	Very Low
Location-Awareness⁺,*	No	Yes	Yes
Support for Mobility⁺,*	Limited	Supported	Supported
Geo-Distribution⁺,*	Centralized	Distributed	Distributed
Real-time Interaction⁺,*	Limited	Supported	Supported
Location of Service⁺	Within the Internet	At the Edge	At the Edge
Distance⁺·*	Multiple Hops	Mostly one Hop	Mostly one Hop
*Hardware**	Large-scale Data Centers with Virtualization Capabilities	Small-scale Data Centers with Virtualization Capabilities	Devices with Virtualization Capabilities (Servers, Routers, …)
Storage Capacity⁺	High	Few	Few
*Computing Capacity**	High	Moderate	Moderate
Permanency of Storing Data⁺	Permanent	Transient	Transient
Geographic Coverage⁺	Global	Local	Local
Response Time⁺	Seconds to Minutes	Milliseconds	Milliseconds
*Availability**	High	Average	High
*Power Consumption**	Relatively High	High	Low

---

[1] Readers who want to visit both referred works, please be advised that there is a naming difference between this work and the works conducted by Habibi et al. (2020) and Yousefpour et al. (2019). Both use the term mobile EC (MEC) for their comparison, which is in this work referred to as only EC. However, all three works do refer to the deployment of small data centers close to the user, as described by the Open Edge Computing Initiative (2023). The naming differences occur as both referenced works describe many more different computing paradigms and therefore distinguish EC as the overall computing paradigm of providing computing resources to the edge and MEC as a special kind of EC (Habibi et al. (2020, p. 69109)) or an extension thereof (Yousefpour et al. (2019, pp. 295–296)).

2.3. Related Research

Current research on FC falls short of answering how FC is connected to organizations business values. This has mainly two reasons. First, applied research focuses on proposing FC architectures for particular use cases or prototyping these. For example, FC architectures for urban water distribution monitoring (Mirzaie et al., 2021), maritime applications (C. Zhu et al., 2022), or remote pain monitoring in e-health (Ilyas et al., 2022) are proposed. These architectures are sometimes described in detail and empirically validated by simulation studies (e.g., for content delivery networks (Alghamdi et al., 2019), for digital twins (Knebel et al., 2021)). For some instances they are also implemented prototypically (e.g., for smart agriculture monitoring (Tsipis et al., 2020), or for the monitoring of pregnant women’s health conditions (Beri et al., 2022)). However, this applied research mostly neglects to elaborate on the value businesses can achieve when adopting proposed FC systems. To enable organizations to decide whether to adopt FC for their business, research must move from discussing single use cases and research prototypes to a more adoption-driven perspective, to elaborate on when FC benefits organizations and can create or enhance their business value.

This may be done by reviewing and synthesizing the applied research already performed. Here, the second reason of shortcomings of current research is relevant. Literature synthesizing this application and prototype literature does not consider FC business values either but focuses on other aspects of FC literature. Table 3 provides an overview of literature reviews on FC considered related research. As this work does neither exclude nor focuses on any type of base literature (e.g., architectural papers) general reviews of FC literature independent of literature type or domain are included. Most of the reviews considered (n=25) were retrieved as part of the literature review process, others were identified beforehand or due to the authors knowledge of their existence (n=3). No additional search for literature reviews on FC was performed. Thus, no comprehensiveness can be claimed for the following description of related research. However, a quick google scholar search (search term: "Fog Computing*" AND "business value" AND "review"; search date: 25th July 2023) was performed to ensure that no literature reviews exist focusing on the exact same topic as this work does. The search revealed two relevant pieces of literature (Perifanis and Kitsios (2022) and Malic et al. (2020)), of which both were already found during the literature review process.

I find that the reviews considered relevant for the most part are concerned with identifying FC characteristics, general architectures, potential application scenarios or challenges identified throughout current literature.

The consideration of FC characteristics serves as a starting point for most literature reviews. However, some stand out in the depth and thoroughness of their research endeavors in this regard. For example, Blume et al. (2022) review 147 FC architecture proposals to identify 11 key characteristics and interdependencies between them. Amongst others, they identify latency, data load, security, interoperability, energy efficiency, and computing power to be important characteristics of FSs.

Table 3: Overview of literature reviews considered related research

Authors (Year)	Description	Review Type	# of Articles	Domain	Characteristics	Algorithms	Technology	Architectures	Applications	Benefits	Challenges and Issues	Adoption / Business Values
Dastjerdi and Buyya (2016)	Overview of FC's characteristics, architecture components, prominent software systems, application areas, and challenges.	n.	-	FC	X			X	X		X	
Byers (2017)	Identification and description of 17 architectural imperatives mapped to different use case settings.	n.	-	IoT	X				X			
Hu et al. (2017)	Review summarizing FC model architecture, applications, key technologies, challenges and open issues.	-	-	FC	X		X	X	X		X	
Varshney and Simmhan (2017)	review of FC literature identifying FC capabilities and potentials as well as the gap to reality.	-	-	FC	X			X	X		X	
Ksentini et al. (2018)	Review of FC architectures with focus on energy consumption and quality of service (QoS).	-	-	FC		X		X				
Aazam et al. (2018)	Comparison of FC and CC based on several characteristics and performance metrics.	-	-	IoT	X			X	X			
Haouari et al. (2018)	Overview of FC, its potentials, architecture, and most significant applications, as well as challenges and research opportunities.	-	12	FC	X			X	X	X	X	
Wadhwa and Aron (2018)	Discussion of FC architecture, applications and concepts to improve smart healthcare systems. Highlighting resource provisioning techniques for FN over utilization identification.	-	-	M/H			X	X	X		X	
Yousefpour et al. (2019)	Comprehensive survey of computing paradigms related to FC. They provide a reference architecture and discuss FC infrastructure from a networking perspective. They further identify 7 potential application subjects.	-	-	FC			X	X	X		X	
Abuseta (2019)	Review of FC's impact on the IoT application development process and architecture considerations based on IoT applications/services.	-	-	IoT	X			X	X			
Raman (2019)	narrative short paper style review of FC in higher education discussing FC characteristics, applications, and security issues.	n.	-	Ed	X				X		X	
Hoque and Hasan (2019)	Review of VFC endeavors to identify the requirements for FC architectures, security, and privacy in this domain and their issues	-	22	VFC				X	X		X	
Antonini et al. (2019)	Review of the most mature architecture initiatives from standardization, commercial, and open-source communities.	-	-	FC				X				
S. P. Singh et al. (2019)	Discussion of a FC taxonomy, differences to CC and EC, FC applications, emerging key technologies (e.g., communication technologies, network function virtualization, etc.) and challenges.	-	-	-	X		X	X	X	X	X	
Malic et al. (2020)	Discussion of factors for FC adoption. They provide architectural elements found for FC architectures. Different models for CC adoption and research are presented.	d.r.	58	FC				X				X
Maharjan and Elchouemi (2020)	Review of FC for smart parking IoT, identifying characteristics, a FC framework, benefits and algorithms.	-	30	IoT	X	X		X				
Caiza et al. (2020)	Study of the most recent architectures, and works on security, latency, and energy consumption of FC in industrial applications. Provides an overview of core concepts in Industry 4.0 settings.	d.r.	-	I4.0	X			X	X			
Yassein et al. (2020)	review of FC primary features and architectural layers. They highlight the benefits of merging IoT, FC and CC.	-	-	FC	X			X	X	X	X	
Habibi et al. (2020)	Comprehensive review of FC, related technologies, architectural aspects, issues and research directions. They provide an overview of FC characteristics and reference architectures and compare them on multiple dimensions.	-	-	FC	X	X	X	X			X	
Haoxin Wang et al. (2020)	Review of FC architectural design alternatives for connected vehicles, including different technologies involved. They derive several design requirements and considerations.	-	-	CV			X	X	X		X	
Sabireen and Neelanarayanan (2021)	In-depth review of FC including FC features, reference architecture, FS algorithms and its combination with IoT.	-	> 16	FC	X	X	X	X			X	
Rani et al. (2021)	Review of FC architecture, characteristics, challenges and benefits.	-	-	FC	X		X	X		X	X	
Abdali et al. (2021)	Development of a taxonomy for FC including technologies, architecture, applications, advantages, and open issues.	d.r.	-	FC	X		X	X	X	X	X	
Blume et al. (2022)	Review of FC architectures to identify the 11 key characteristics and 39 interdependencies (synergies or trade-offs).	d.r.	147	FC	X							
Perifanis and Kitsios (2022)	Review of impacts of FC and EC for IoT solutions on organizations business value streams. They identify FC and EC as value drivers for IoT and positive/negative effects of IoT solutions.	d.r.	124	IoT	X					X	X	X
Quy et al. (2022)	Comparison between CC and FC for healthcare. Healthcare FC proposals are classified into three approaches, performance improvement, privacy and security, and offloading.	-	13	M/H			X	X	X		X	
Subedi and Sharma (2022)	Discussion of FC architectures, features supported by these architectures, applications, and security issues.	-	-	FC	X			X	X	X	X	
Das and Inuwa (2023)	Presentation of a FC taxonomy of security challenges, service issues, operational issues, and data management.	d.r.	48	FC	X			X	X		X	

Legend

Description:	Short description of the review endeavor
Review Type:	Type of review either stated directly or inferred n. = narrative type review; d.r. = database review; - = not stated / could not be inferred
# of Articles:	Number of articles within the review if stated or could be inferred, else: - = not stated
Domain:	FC = Fog Computing; IoT = Internet of Things; VFC = Vehicular Fog Computing; CV = Connected Vehicles; M/H = Medical/Healthcare; Ed = Education; I4.0 = Industry 4.0

They identify several interdependencies between their key characteristics, which are classified either as synergies or as trade-offs, taking multiple characteristics into consideration to guide future research in that area. Das and Inuwa (2023) identify 13 characteristics (including low latency, heterogeneous end-user support, mobility support, real-time interaction, and wide geographical distribution) and 24 topics (including load balancing, offloading, quality of Service (QoS), security, and context-awareness) in FC research.

However, reviews considering FC characteristics do not build on the identified characteristics to show how organizations can use them to achieve business value.

Most related research also considers architectures and application subjects. Dastjerdi and Buyya (2016), for example, propose a reference architecture consisting of five layers and showcase several potential FC applications in healthcare, smart utility services, and gaming. Sabireen and Neelanarayanan (2021) use several reference architectures to derive their FC framework consisting of seven layers including, for example, monitoring, pre- and postprocessing and security layers. They further discuss FC and IoT together with application scenarios therein. Yousefpour et al. (2019) discuss seven subject areas they found as objectives in FC application papers, namely data stream processing, bandwidth savings, data analytics, healthcare, video and game analytics, image and face recognition, artificial intelligence and machine learning. Furthermore, open research issues and challenges are discussed by these reviews. Even though they are concerned with describing how FC is used in research endeavors, they do not comprehensively describe in which ways FC can aid organizations to reach business-related goals.

Yousefpour et al. (2019), Habibi et al. (2020), and Aazam et al. (2018), further, discuss technologies related to FC, such as CC or EC and contrast them comprehensively to FC. However, they do not tailor their comparison to the needs of organizations looking for guidance in their decision for one or the other computing paradigm.

More closely related to this works research are the reviews of Perifanis and Kitsios (2022) and Malic et al. (2020). Perifanis and Kitsios (2022) investigate the impacts of FC and EC for IoT solutions on organizations business value streams through a systematic review of 124 articles. They identify FC and EC as value drivers for IoT and several positive (e.g., reduced latency, cost, etc.) and negative effects (e.g., disruption) of IoT solutions in organizations. However, their conceptual framework of value mapping and, thus, their value generation streams are limited to IoT applications. This work sets out to investigate FC business value creation on a broader scale, not limited to IoT settings. Furthermore, not the business value of employing IoT services aided by FC shall be considered, but the value that can be created by relying on FC as a technology itself.

Malic et al. (2020) identify and discuss factors for FC adoption. Different models for CC adoption are presented and research gaps identified for FC adoption. However, their FC adoption gaps are mostly related to FC capabilities. Even though they analyze cloud adoption models and discuss their factors, no concrete business values are presented and discussed. Furthermore, no connections between business values and capabilities are drawn.

Having looked at both applied research and synthesizing literature, I find that this works aim of identifying how FC can be used by organizations to create business value is not yet answered by existing research. Even though parts of this works sub-objectives (e.g., the identification of FC capabilities, which are considered FC affordances for this work) are already present in synthesizing literature, they are not linked to business values as no research on such business values in the general field of FC exists. Furthermore, no affordance theoretical point of view could be identified, which further separates this work from previous research.

3. Methodology

To reach the sub-objectives and answer the research question of this work, a data collection in form of a literature review (step 1) was performed, followed by data analysis. For the review six databases were queried resulting in 58 articles included in the review. The data analysis of these articles comprises two steps, a thematic analysis (TA) (step 2) and the subsequent identification of business values creation sets (BVCS) (step 3). Step 2 resulted in 61 affordances grouped under four top-level themes, 12 service types grouped under three top-level themes, and 32 business values grouped under four top-level themes. In total, eight BVCSs could be identified in step 3. Figure 2 provides an overview of the research process. The three steps are described in detail in the following subsections.

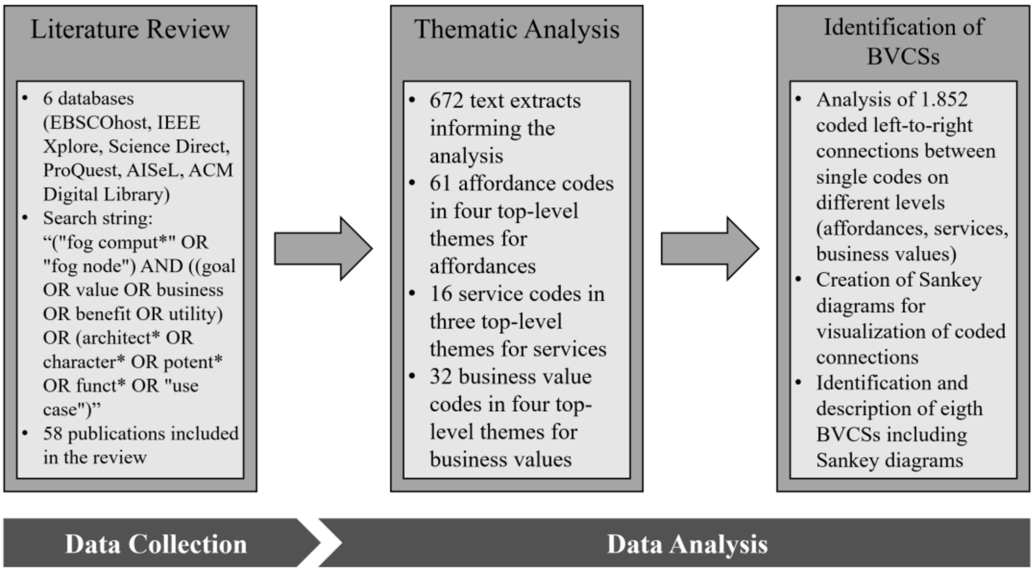


Figure 2: Overview of the research process

3.1. Data Collection –Literature Review Process

For data collection a literature review relying on guidance from the IS discipline (Brocke et al., 2015; Webster & Watson, 2002) was conducted.

As the subgoals of this research include identifying FC capabilities and functionality, and FC business values, the search string used needed to reflect that. To achieve that a “three-column” approach was chosen, which each “column” representing a certain facet of the search. Table 4 provides an overview of the terms the search string consists of. The first column limits the scope of this review to literature concerned with FC and consists of the terms “fog comput*” and “fog node”. This column sets the overall setting of the search and is thus mandatory for every search result. The second column is concerned with limiting the search to business values. It contains search terms like “value”, “business”, “benefit”, and “utility”. The third column consists of terms for capabilities and functionality of FSs and therefore contains the terms “architect*”, “character*”, “potent*”, “funct*”, and “use case”. As this review sets out to uncover connections between FC capabilities and the business values FC may provide, it cannot be assumed that current literature already provides both types of information readily available to query for in a database. Thus, having terms of the second or third column was considered sufficient for the search term.

Table 4: Overview of search terms the search string consists of

Fog Computing Terms	Business Value Terms	Capability Terms
“fog comput*”	goal	architect*
“fog node”	value	character*
	business	potent*
	benefit	funct*
	utility	“use case”

The search string was created by querying *EBSCOhost,* trying to balance the breadth of the review and obtaining a manageable set of literature. In the later stages of the search string creation process, the size of the *EBSCOhost* result set was cross-checked with *Science Direct* to ensure that the search string is not only valid for *EBSCOhost* and does not lead to only a few hits in other databases or too many to handle during the review.

The finalized search string reads as follows: “("fog comput*" OR "fog node") AND ((goal OR value OR business OR benefit OR utility) OR (architect* OR character* OR potent* OR funct* OR "use case")”. To find relevant literature, the following databases, covering a broad set of literature from different areas, were queried: *EBSCOhost* (*Academic Source Premier* and *Business Source Premier*), *IEEE Xplore*, *Science Direct*, *ProQuest*, *AISeL*, and *ACM Digital Library*. To obtain a manageable literature set, the search string was applied to document titles only.

Except for *Science Direct,* this search string could be directly used for querying the databases. An adaption was necessary for *Science Direct* as no wildcards (“*”) were allowed in *Science Direct* search strings and the number of terms that could be queried for was limited to eight in total. To cope with that and still comply with the usage of wildcards for other databases, the query was split into three and different endings were used for the search terms containing wild cards (e.g., “characteristic OR characterization OR characterizing” instead of “character*”). Only literature in English language was considered for this review to ensure the readability and understandability. Other than that, no further restrictions were made, and no further filters were applied. A discussion on that can be found in the limitation (section 5.3).

An overview of the steps carried out for the subsequent literature review process can be obtained from Figure 3. For the following text, the numbers in brackets refer to the corresponding part of Figure 3.

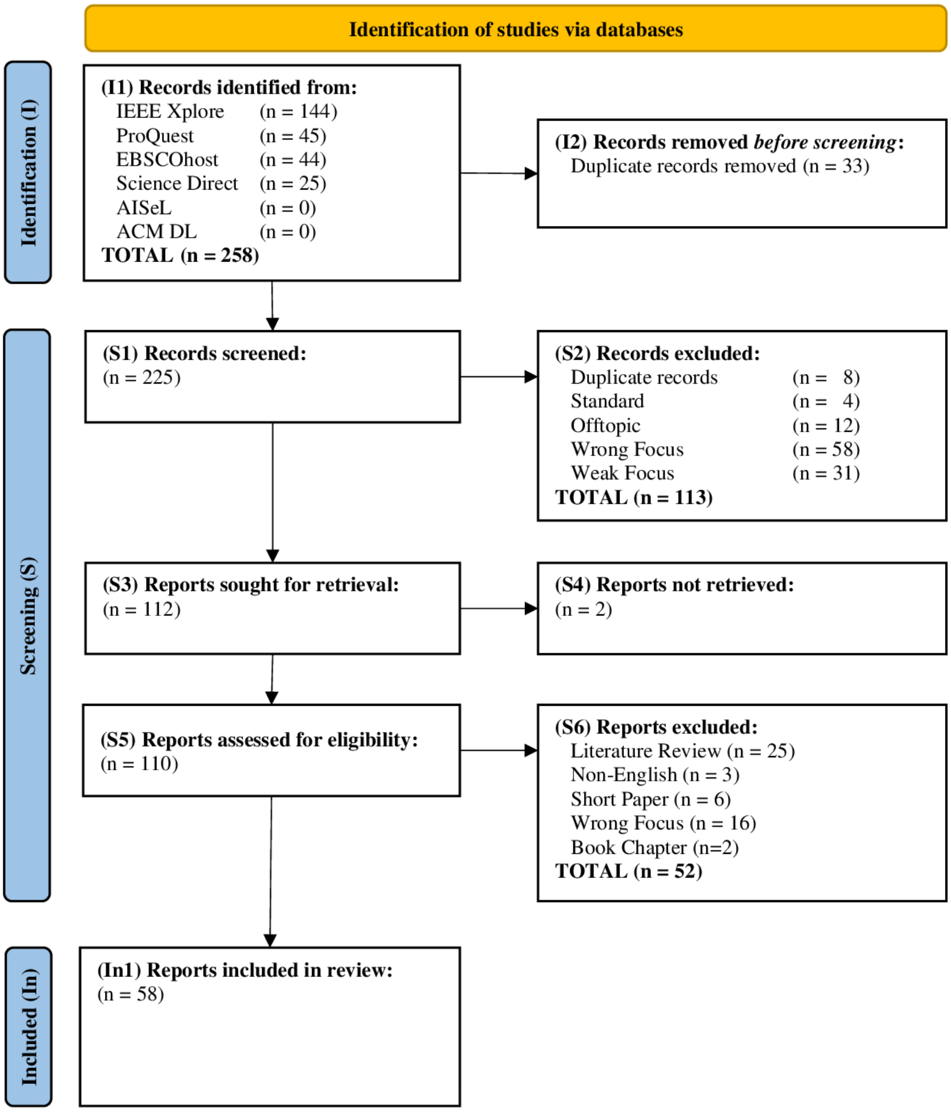


Figure 3: Overview of the literature review process in the style of a PRISMA flow chart (adapted from Page et al. (2021))

The search, conducted on March 17th, 2023, resulted in 258 records identified from the six databases (I1). Thereafter, duplicates (n = 33) were automatically removed (I2) by importing the search results into a citation program (Citavi) project, without importing project duplicates.

The remaining 225 records were then screened for relevance (S1), taking the document title and abstract into consideration. Table 5 provides an overview of relevant exclusion criteria for the screening step.

In this step a total of 111 records were excluded (S2) as not relevant for the review. Eight were further duplicates (e.g., because of having a preprint and the associated subsequently published full paper in the set of records). Furthermore standards, drafts of standards, and reports of standard adoption were excluded from the review (n = 4) as they were not accessible for the authors at the time of the review and are too generic for the purpose of this study. Another 12 records were excluded as “offtopic” as they do not discuss or focus on FC but focus on other topics. They only mention FC or are mainly concerned with, for example, the creation of algorithms for FC and other technologies or the placement of virtual machines on FNs.

59 records were excluded for having a “wrong focus”, as they did focus on FC, but no indication of a discussion of FC capabilities or business values could be found in the document title or abstract.

Finally, 31 records were excluded for having an unclear or only weak indication of FC capabilities or business values in document title or abstract. These articles may potentially bring new insights on FC capabilities and business values but were nevertheless excluded as the number of records for eligibility assessment was still high. This decision is later justified by still having 58 articles informing the review and reaching theoretical saturation in the performed data analysis.

Table 5: Overview of exclusion criteria for the screening (S2) and eligibility assessment (S6)

Criterium	Description	# Excluded
(S2) Screening		**113**
Duplicate Records	Records that are duplicates to other records in the project (e.g., because of having preprints and subsequently published full articles in the results set) that were not automatically removed beforehand.	8
Standard	Standards or reports about standards that are too generic or do only state that a certain standard was adopted (e.g., OpenFog Reference Architecture adopted for IEEE Standard).	4
Offtopic	Records not focusing on FC per se but on other topics that are related to FC yet not in scope for the review (e.g., optimal placement of virtual machines on physical machines).	12
Wrong Focus	Records that focus on FC but do not provide any indication in title or abstract that FC capabilities or business values are discussed (e.g., development of task scheduling algorithms for FC architecture without any indication of FC capabilities used or business values achieved with this in title or abstract).	59
Weak Focus	Records that focus on FC but do only provide weak or unclear indication in title or abstract that FC capabilities or business values are discussed.	30
(S6) Eligibility Assessment		**52**
Literature Review	Reports representing literature reviews on FC as a technology or reviews of architectures that do not provide any own architecture or capabilities / business values.	25
Non-English	Reports which’s full text is non-English, and no English version is available to the authors.	3
Short Paper	Reports that do not have the length or means to describe FC capabilities or business values sufficiently or are work in progress.	6
Wrong Focus	Reports that do not describe FC capabilities or business values in sufficient depth or detail (e.g., only naming FC capabilities without description of how these are used / incorporated in the architecture).	16
Book Chapter	Reports representing book chapters on FC as a technology. Not a conference paper or journal article.	2

This left 112 reports for retrieval (S3) after the screening, of which two could not be retrieved (S5).

The remaining 110 reports were then assessed for eligibility (S5). Table 5 provides an overview of relevant exclusion criteria for the eligibility assessment. During the eligibility assessment literature reviews of FC (e.g., literature review of FC technology, review of FC architectures, etc.) were excluded (n = 25), as they do not provide own FC capabilities or business values but do only report the ones described in existent literature. Moreover, reports which's full texts were not available in English were excluded as "Non-English". This was the case for three reports, even though their titles and abstracts were in English, which is why they were not excluded in the screening step (S1/2) beforehand. Also, reports representing short papers or work in progress papers were excluded (n = 6) as they do not have the length nor the means to describe FC capabilities or business values in detail. For a similar reason another 16 reports were excluded as "Wrong Focus", as they did not provide sufficient description for either of FC capabilities or business values, but only referred to them without further examination. Furthermore, two reports were excluded for being "Book Chapters", as book chapters are typically not peer-reviewed and could, thus, for example, be biased towards the authors opinion.

This left 58 reports, surviving the eligibility assessment, to inform the review (In1).

For these 58 reports, comprehensive meta information was recorded in an excel sheet. For all other records and reports, at least brief meta information, such as authors, title, year of publication, and the decision on inclusion or exclusion, were recorded. A forward or backward search was not performed, as the final set of literature was already extensive. An overview of all 58 reports including author names, title, year, research domain, research approach, and validation status of the reports' findings is provided in Appendix A. Descriptive results of the included literature are provided in section 3.2.2 within the description of *Phase 1* of the TA.

3.2. Data Analysis – Affordance Theory, Thematic Analysis and Identification of Business Value Creation Sets

3.2.1. Affordance Theory as a Theoretical Lens

To enable the identification of capabilities and business values FC proposes to organizations, affordance theory shall be used as a theoretical lens. Originating in the psychological literature (see Gibson (1977)), affordance theory and the concept of affordances have been used in IS literature in several recent studies to explore the value of digital technologies and how to realize such values through affordance actualization (Dremel et al., 2020, p. 2). Affordance theory offers a lens to identify the affordances of an IT artifact or technology (Volkoff & Strong, 2018, p. 11) and, thus, a starting point to investigate how business value may be achieved by actualizing these affordances (Dremel et al., 2020, p. 2). For the context of IS an affordance is defined as "the potential for behaviors associated with achieving an immediate concrete outcome and arising from the relation between an artifact and a goal-oriented actor or actors" (Volkoff & Strong, 2018, p. 4). Affordances, thus, always arise from the relation between artifact and user and not from the artifact itself on its own. Furthermore, as affordances are a potential for a specific behavior, one must distinguish between the affordance and its actualization, which describes the concrete action taken based on the affordance. The relationship of actor, goal, artifact and the affordance, as well as the necessity for actualization to reach an outcome as described by Huifen Wang et al. (2018, p. 65) are depicted in Figure 4. However, for this work only the left side containing actor, artifact, goal and affordance is of relevance, hence the rest of the figure, which is not of relevance, is greyed-out.

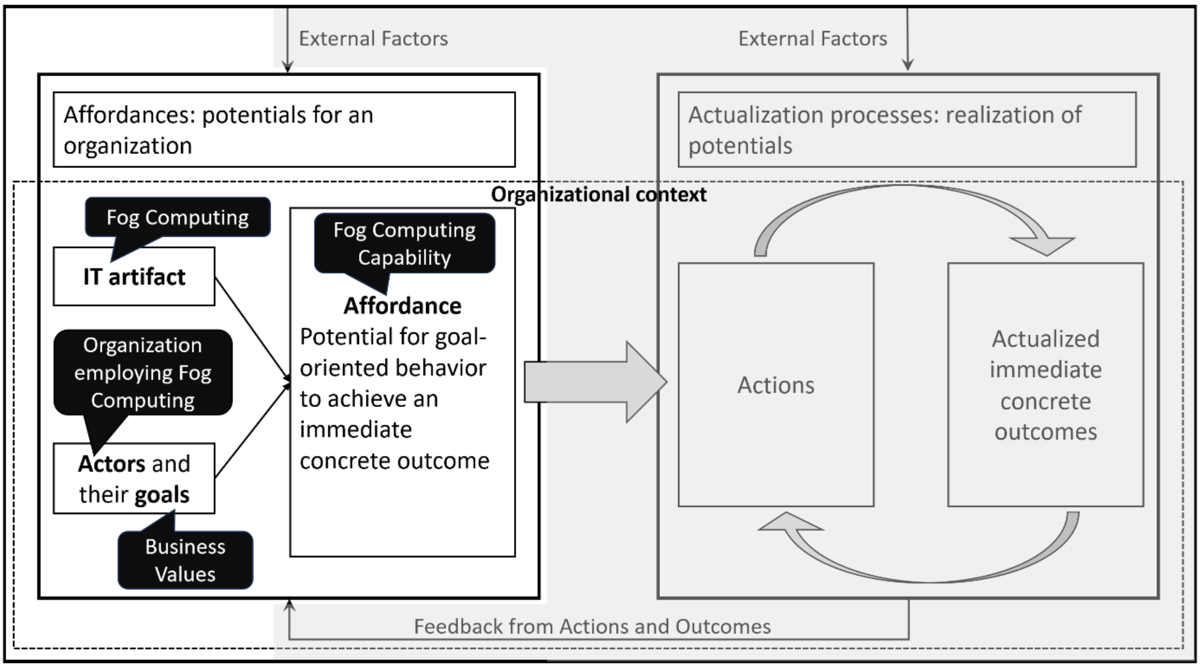


Figure 4: Affordances and their actualization process (adapted from Huifen Wang et al. (2018, p. 65))

Figure 4, furthermore, shows the relationship between the setting of this research endeavor and the terms used in affordance theory. First and foremost, the IT artifact of interest is FC. By relying on affordance theory, potential business values can be identified as the goals different actors try to achieve. An actor for the purpose of this research is any organization employing FC for any part of their business. However, this research is not concerned with companies offering FC infrastructure to other companies as an IT service provider, as the business value (financial rewards for the provisioning of the system) is rather clear in this case. I furthermore can link FC capabilities to business values by regarding them as affordances FC offers to these actors. As affordances only arise from the relation of an artifact or technology and an actor (Volkoff & Strong, 2018, p. 4), it is necessary to distinguish between different actors (e.g., users of the system, organizations providing and operating FSs, organizations providing for example vehicles that are part of the FS, etc.) involved in a FS and the affordances they are offered by the system. As already stated above, this work only considers this relationship for organizations making use of FC as part of their business.

3.2.2. Using Thematic Analysis for the Identification of Affordances and Business Values

To identify FC capabilities as affordances and business values as actors' goals, the publications identified in the literature review were analyzed by applying TA following the guidelines proposed by

Braun and Clarke (2006). TA is a six-phased method that allows for the identification, analysis and reporting of patterns, so called themes, in the data and it is widely used in qualitative research (Braun & Clarke, 2006, p. 79).

Table 6 provides an overview of the six phases, slightly adapted from Braun and Clarke (2006, p. 87), as data transcription in *Phase 1* is not necessary due to working with literature. The following paragraph describes how TA was used for this research and refers to the six phases and their extensive description in Braun and Clarke (2006, pp. 87–93).

Table 6: Phases of thematic analyses (adapted from Braun and Clarke (2006, p. 87))

Phase	Description of the process
1. Familiarizing yourself with your data	Reading and re-reading the data, noting down initial ideas.
2. Generating initial codes	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
5. Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6. Producing the report	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

In *Phase 1,* the researcher is to familiarize themselves with the data to "immerse [themselves] in the data to the extent that [they] are familiar with the depth and breadth of the content" (Braun & Clarke, 2006, p. 87). This may require repeated reading of the whole data set, however, at least one pass of the entire data set is recommended. Due to the extent of this review incorporating 58 reports, reading through all reports once before analysis was not feasible. To still facilitate some degree of familiarization with each data item (publication) before generating initial codes for it, every publication was scanned for important sections once, which also allowed for grasping the overall research setting and main results of each data item. To foster the familiarization the research domain, approach, method, and type of validation used to support main findings was recorded alongside comments on contribution. This information adds to the extensive meta information provided for the 58 reports in Appendix A.

Figure 5 provides an overview of the year of publication, the primary domain, the validation status, and the document type of the publications included in the review.

The publication year ranges from 2013 to 2023. There is an increase in articles, up to 2020, with most articles being published in the years 2018 – 2020. The small number of articles for the years before 2018 may be due to the term "fog computing" being first used by CISCO in 2012 (Patel & Patel, 2022, p. 66). Research may have needed some time to pick up FC as an interesting topic to elaborate on. From 2021 on the number of articles decreases steadily. This may have several reasons. First, the focus of research may have shifted from describing FC applications, characterizing FC, or proposing architectures towards discussing more specific problems within FC research (e.g., describing specific algorithms or the placement of virtual machines on FNs). Such studies, however, were excluded for this review. This is supported by looking at the years of publication for all initially found literature. Still decreased publications for the year 2021 can be observed, but with more articles being published in 2022 again. For the year 2023, the small number of reviewed articles may be explained by having conducted the search at the beginning of the year.

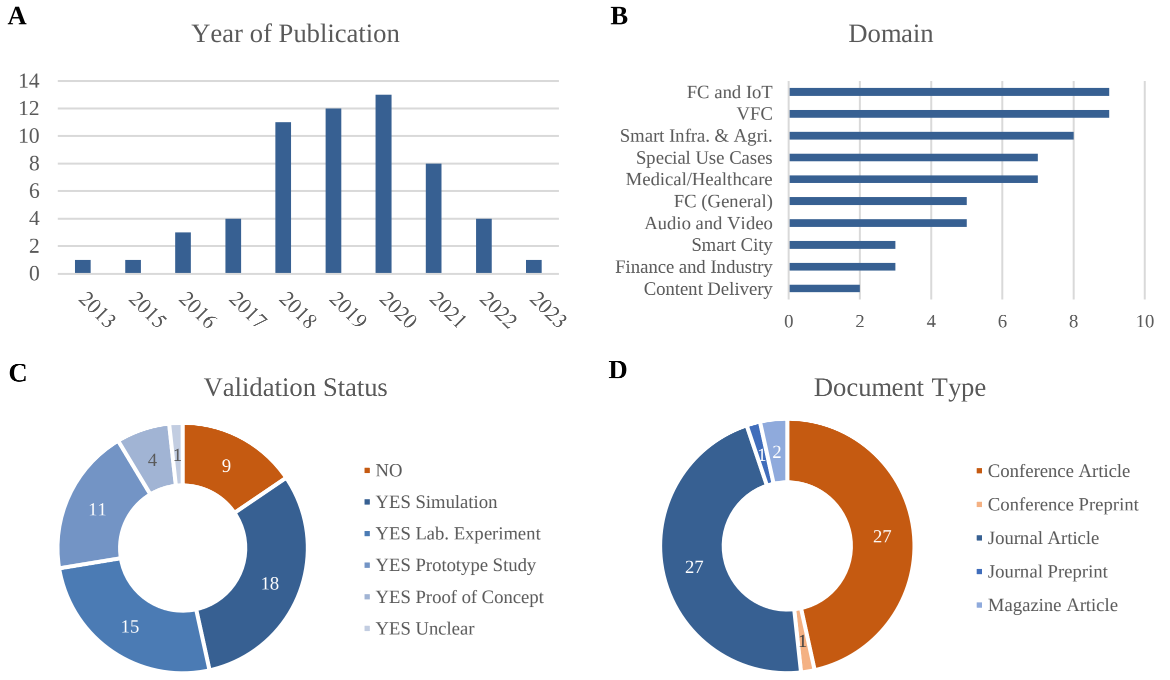


Figure 5: Years of publication (A), primary domain (B), validation status (C), document type (D) of included publications

To familiarize with the contexts the included publications are set in, the primary domain of interest was identified for each publication. The most publications were combining *FC and IoT* or conducting research in the field of *VFC*. Second to this, the domains of *smart infrastructure and agriculture* (including, e.g., smart grid applications) is found. *Medical / healthcare* and *special use cases* are found positioned third. *Special use cases*, however, is combining work that focuses on rather specific use cases that could not be placed in other domains (e.g., FC for space technology, maritime applications, or disaster management). Five publications consider FC in general without focusing on any domain.

Most (49 of 58) of the publications included provide some kind of validation for the claims made for their research. *Simulation studies* (n = 18) are the most prominent type of validation. Here I find that five out of these studies use *iFogSim*, which is a toolkit for the modeling and simulation of resource management techniques in FC among others (Gupta et al., 2017). 15 articles use *laboratory studies* for their validation by setting up FNs in a laboratory style. For example, testbed environments based on desktop computers are created (e.g., H. Zhang et al. (2020), Jalowiczor et al. (2021)). However, especially with this kind of validation, often only the impact or performance of algorithms used on top of the proposed FSs were validated (e.g., Nurnoby and Helmy (2023), P. Wang et al. (2018)). Other publications implement real-world prototypes in realistic settings for the validation of their architectures (e.g., Beri et al. (2022), Tsipis et al. (2020)).

Considering the document type of included publications, one can see that the ratio of publications presented at conferences and articles published in journals or magazines is almost balanced. This works findings, thus are based upon a balanced set of conference and journal articles. Two preprints were included into the review, one submitted to a journal, and one retrieved from a conference. The conference preprint was later published almost unchanged. The journal preprint, however, has not been published so far. Two articles were published by the IEEE Communications Magazine. As this magazine focuses on delivering practical information on hot topics, implementations, and industry practices and this work takes an organizational point of view it was decided to still include the articles.

Paying a closer visit to the conferences present in the review, no conference sticks out. For journals, I find, that five outlets are represented several times (*Wireless Communication and Mobile Computing* (n=5), *IEEE Access* (n=4), *Sensors* (n=3), *IEEE Transactions on Industrial Informatics* (n=2)).

All included publications, except for one, are primarily concerned with architecture design. The other one is concerned with algorithm design, but still provides interesting insights for this work. The reason for the majority of articles being architecture design, may lie in the search terms including “archtectur*”.

Phase 2 of the TA process is intertwined with *Phase 1* for this review. In this phase interesting features of the data are assigned labels (codes) in a systematic way and across all data items. Codes were developed iteratively and in an inductive way, meaning that once an interesting feature was identified in a text passage, it was assigned a code. This could either be a code already existing, in case the feature identified matches with the meaning of the code, or a novel code was created. To reach the first two subgoals of this work, the interesting features coded for are twofold. A first unit of analysis are FC capabilities, seen as affordances FC provides to organizations. A second unit of analysis are the business values these actors are aiming to achieve by relying on FC. Both units of analysis are coded for separately, using an excel spreadsheet documenting a unique identifier (ID) for every occurrence of a code, the publication ID, and pages they can be found at, the text passage they are described in and a name. For example, the text extract “[…] [w]ith cooperation among different players, a new business ecosystem could be constructed […]” (C. Zhu et al., 2022, p. 32), was coded for the business value ‘new business eco system’ (Ex. 225_32), and the text passage “[…] acquire data from a wired or wireless sensor network, locally process the gathered data […]” (Brzoza-Woch et al., 2016, p. 2) was coded for the FC affordance ‘locality’ (Ex. 153_2). During the coding process of the first reports, it was found that there is a third feature that should be coded for, residing between the affordances and the business values. It became apparent, that the FC affordances are not necessarily directly leading to certain business values. However, they are used to provide specific kinds of services, which in turn are used to generate business values for the organizations, as they are used to reach a goal by relying on FC. This is why the third feature was named “services”. Figure 6 shows how the three features coded for work together with the elements of affordance theory.

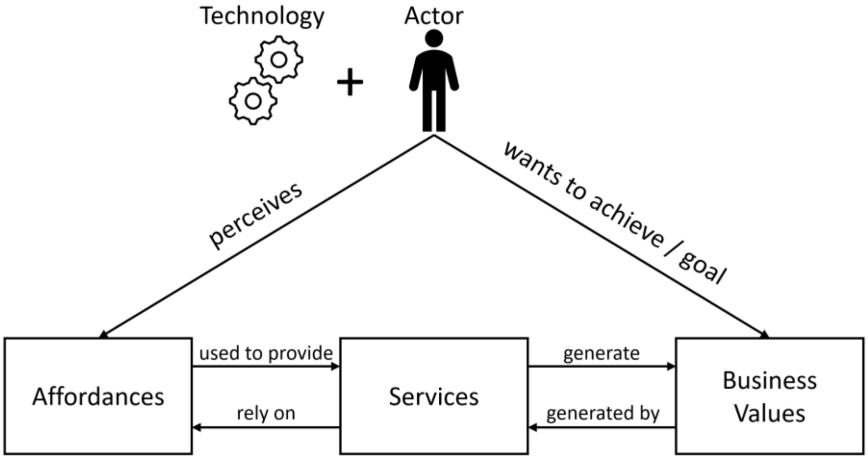


Figure 6: Relationship between affordances, services, business values, and the used elements of affordance theory.

Phase 2 resulted in 61 codes for affordances with 934 overall occurrences, 15 codes for services with 240 overall occurrences, and 36 codes for business values with 163 overall occurrences. For all codes a brief description was created during coding to ease the process of deciding whether a code can be reused for a text passage capturing an interesting feature. The descriptions and coded occurrences were reviewed after coding of 50% of the publications and after coding all of them to ensure the consistency of the coding process.

For *Phase 3* the identified codes were iteratively grouped into themes by relying on the descriptions developed in *Phase 2*. To ease the creation of themes, codes were already initially assigned to initial themes during *Phase 2*. For example, the affordance code 'locality', among others, assigned in Ex. 153_2, was initially assigned to a *locality* theme consisting of locality, 'localization', 'edge location', and 'location-awareness'.[2] These initial assignments were reviewed alongside the coding consistency review after 50% and at the end of the coding process taking all data extracts available at these stages into account. Using this initial assignment, themes were aggregated from codes bearing the relationship between codes, themes, and different levels of themes in mind. For visualization purposes a mind map for each of affordances, services, and business values were used. For the second half of the articles, only two additional affordances and eight additional business values could be found, which could be grouped under existing (sub-)themes, indicating a certain level of theoretical saturation. Thus, the data collection decision of not reviewing the 31 articles with only weak focus can be justified.

Phase 4 is concerned with reviewing the themes. This involves two steps of review. The first step reviews the themes at the level of the coded data extracts. The coded extracts for each theme should form a coherent pattern. If not so, either the theme needs reworking, new themes need to be created or the data extracts not fitting the theme need to be reassigned. This was done alongside the coding consistency reviews. During this step, the previously mentioned *locality* theme was merged with *contextuality* to form a *contextuality & locality* theme, as it was discovered, that the affordances

---

[2] Please note, that the affordance code 'localization' was later merged with 'location-awareness', as it was describing the same feature but under different name and both were placed in the same initial theme.

location-awareness and context-awareness placed in the themes are often discussed intertwined and are strongly connected thematically. The resulting thematic (mind) maps after the first consistency review (50%) are provided in Appendix B and the thematic maps after the second consistency review at the end are provided section 4.1. The second reviewing step is concerned with theme validity in relation to the entire data set. This step involves re-reading the data set to ensure that the themes fit the data set and to code any additional data within the themes that was missed in earlier rounds of coding. Due to the large number of publications in this review, the recoding was only done for themes that only appeared in later stages of the review. For example, a substantial number of codes for the business value theme “Business Optimization” became apparent after analyzing about 1/3 of all reports. Thus, all reports analyzed beforehand were re-visited and analyzed for “Business Optimization” codes. This approach does, however, not ensure that no themes were missed, yet it provides a reasonable tradeoff between comprehensiveness and feasibility.

In *Phase 5* of the thematic analysis process themes are defined and named. This does not only involve finding a concise name for each theme, but also identifying the essence of each theme and what is of interest about them and how they are related to other themes. This was done by considering each theme and trying to “describe the scope and content of each theme in a couple of sentences” (Braun & Clarke, 2006, p. 92). Exiting *Phase 5* four top-level themes for affordances, three top-level themes for services and four top-level themes for business values had been identified.

Phase 6 is concerned with producing the research report. This includes providing sufficient evidence in form of data extracts and vivid examples.

3.2.3. Identification of Business Value Creation Sets

As this work does not only set out to identify themes in FC affordances, services, and business values, but further wants to investigate how these are related with one another (sub-goal three), the relations between affordance, service, and business value themes needs to be uncovered. This is done by relying on information additionally coded in *Phase 2* of the TA. For every occurrence of a code for one of the features coded for (affordances, services, business values), it was coded with which codes from the respective other features they are related. This was done by not only taking the concrete data extract into account, but also the overall setting of the record it is taken from. For example (Ex. 195_3), the affordance code ‘preprocessing’ for the text passage *“As a kind of distributive calculation approach, each fog node is able to preprocess the data received and extract their features independently, i.e., different structural feature extraction or feature combination are performed on different fog nodes or datum according to different audio are processed on separate nodes, FC is wonderfully applicable for transmission of quantities of audio datum and complicated tasks”* (W. Chen et al., 2019, p. 3) was associated with the service codes ‘data-intensive services’ and ‘latency-sensitive applications’, even though no service was mentioned in the concrete data extract. The overall aim of the publication though, was to create an audio search model, described to be very data-intensive and latency-sensitive by the authors.

This additional coding information was then used to connect the themes for affordances, services, and business values on a higher theme level. Therefore, in a first step, all code instances that did not reveal any connections (e.g., only an affordance was coded, but no connection to any service) were removed for this data analysis step (n=290). This left 1.075 code instances for further analysis. As multiple connections may be coded for a code instance (see, e.g., Ex. 195_3), code instances were copied to retain a single connection per code instance (copy). For the case of Ex. 195_3, two combinations were retrieved for the text extract: preprocessing and data-intensive services and preprocessing and latency-sensitive applications. Like this, 1.956 single-connection instances were retrieved from the 1.075 starting code instances.

As sometimes coded connections are not pointing in the correct flow direction, for example, because for a service code connected affordances were coded, these connection directions needed to be reversed. While doing so, one coded connection within the affordance level, ten coded connections within the service level and three coded connections within the business value level were identified and deleted, leaving 1942 code instances. The reversing of coded connections' directions led to 90 duplicates (Paper_ID, pages, text extract, connection source code, connection target code), which were removed via automated duplicate detection in Excel, leaving 1.852 coded connections. No manual duplicate removal was performed, due to feasibility.

Then the number of occurrences for every combination of connection source code and connection target code was calculated using pivot tables. For the calculation of existing combinations and their number of occurrence, excel power queries for building every combination of the existing connection sources and targets from the pivot table and then reading the number of occurrence for every combination from the pivot table were built. In total 3.060 combinations of existing connection source codes and target codes were built, of which 451 had non-zero occurrence values.

These non-zero combinations were then prepared for import into SankeyMATIC.com using the descriptions of SankeyMATIC.com creator Steve Bogart (n.d.), to create a Sankey diagram for better visualization and overview of the identified connections. The resulting Sankey diagram turned out not being very useful, as it is crowded and the connections cannot be very well observed, even though automatically sorted for best visibility. Therefore, and for purposes of better results discussion and level of aggregation, the themes identified via TA were used to display the affordances and business values.

As only 15 service codes were identified (including Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) as services, as there are connection codes for these, even though they emerged to be top-level service-themes) further aggregation for the services was not performed. This revealed 29 coded source services / themes and 23 coded target services / themes that form a total of 667 combinations. From these 209 were non-zero. They were prepared for import into

SankeyMATIC.com like before. All codes and level-one sub-themes were color-coded and displayed in order of themes.

As the Sankey diagram reveals the connections graphically, eight candidate BVCS on the level of level-one sub-themes became visible by following greater flows throughout the diagram. As the connections between affordance themes and service themes are manifold, for this step all possibly feasible connections were included (depending on the strength of connection). For example, the affordance theme *applications* did not make it into any candidate BVCS, as its connections to the service level are too few and weak. For the identification of possible sets on service and business value level the percentage of connections outgoing from each service theme to each business value theme and incoming vice versa were calculated. Only connections with a high percentage in both directions were included in candidate BVCSs. Like this, for example no connection from *data-related services* to *time* business values was included as only 11,11% of codes to *time* were coming from *data-related services* and only 1,67 % of outgoing *data-related services* connections were flowing towards *time*. The candidate BVCSs are shown in Table 7 below. The aforementioned Sankey diagram is displayed and described in section 4.2. Connections that were directly reaching from the affordance level to the business value level were not included in any BVCS, due to the reasons discussed in section 4.2.

Table 7: Overview of the candidate BVCSs

ID	Candidate Affordances Themes	Candidate Service Themes	Candidate Business Value Themes
BVCS01	*Data Acquisition*, *Data Processing*, *Data Storage*, *Data Transmission*, *Contextuality & Locality*, *Network Properties*	*Data-Related Services*	*Business Optimization, Financial*
BVCS02	*Data Acquisition*, *Data Processing*, *Data Storage*, *Data Transmission*, *Contextuality & Locality*, *Network Properties*, *Communication*	*Latency-Related Services*	*Business Optimization*
BVCS03	*Data Acquisition*, *Data Processing*, *Data Storage*, *Data Transmission*, *Contextuality & Locality*, *Network Properties*, *Distributed System*	*Locality & Contextuality*	*Business Optimization, Financial*
BVCS04	*Data Acquisition*, *Data Processing*, *Data Storage*, *Data Transmission*, *Contextuality & Locality*, *Network Properties*, *Communication*, *Autonomy & Management*	*Platform as a Service*	*Business Optimization, Society*
BVCS05	*Data Acquisition*, *Data Processing*, *Data Storage*, *Data Transmission*, *Contextuality & Locality*, *Network Properties*, *Communication*, *Autonomy & Management*, *Privacy, Safety, & Security*	*Infrastructure as a Service*	*Connectivity*
BVCS06	*Data Acquisition*, *Data Processing*, *Data Storage*, *Data Transmission*, contextuality & locality, *Network Properties*, *Communication*	*Latency-Related Services*	*Privacy, Security & Transparency, Time*
BVCS07	*Data Acquisition*, *Data Processing*, *Data Storage*, *Data Transmission*, *Contextuality & Locality*, *Network Properties*	*Data-Related Services*	*Society, Sustainability*
BVCS08	*Data Acquisition*, *Data Processing*, *Data Storage*, *Data Transmission*, *Contextuality & Locality*, *Network Properties*, *Communication*	*Latency-Related Services*	*Society, Sustainability*

The candidate BVCS identified like this were then queried against the coded connections to have a closer look at them. For each of the candidate BVCS, the amount and percentage of connections between the level-one subthemes were portrayed and analyzed. Only the most important connected level-one subthemes were kept within each candidate BVCS. For example, for BVCS02, at first having *data storage* as an affordance theme looked promising. However, analyzing the connection data showed, that it did not contribute much to the overall discussion on this. Only 7.51% of coded connections from affordance level to service level for the candidate theme were concerned with data storage and none of the service codes for the service themes involved was specially strongly connected with this theme. *Data acquisition* on the other hand was kept for the BVCS although over all being less coded than *data storage*, as it was one of the top-three coded connections for the *latency-related service* ‘near-real-time service’.

No candidate theme was pruned, although some of them (e.g., BVCS05) have only little overall support in the coded connections. The resulting BVCS are shown and briefly presented in section 4.2.

4. From Affordances to Business Value Creation

4.1. Description of Themes as Basis for the Business Value Creation Sets

4.1.1. Fog Computing Affordances

In total, four top-level themes for FC affordances could be identified through TA, namely (AT1) “Data”, (AT2) “Network”, (AT3) “System Properties”, and (AT4) “MICS Affordances”, of which the last one holds affordances that could not be grouped under any other theme. The four themes are subsequently subscribed. Each one of the 58 articles in the review was associated with affordances at least two times. Appendix C provides a graphical overview of the identified themes, sub-themes, and affordances in form of a mind map. Appendix D provides an overview over all publications’ contribution to affordance, service, and business value themes.

Theme AT1: Data

In the reviewed literature I find that FC provides 21 “Data”-related affordances. FC is thereby used for *data acquisition*, *data processing*, *data transmission*, and *data storage*. Table 8 provides an overview of all “Data” affordances in their respective sub-themes, with a short description, an indication of their validation status (o/+) in the investigated text extracts, and up to four exemplary publications.

The sub-theme *data acquisition* is concerned with FC being a means for the collection and gathering of data. FC allows for ‘multi-source data acquisition’, meaning the gathering of data from multiple heterogeneous sources in varying quality, volume, and data kind. Each FN is thereby responsible for the data gathering in its vicinity (Hassan et al., 2020, pp. 7–8; W. Zhang et al., 2017, p. 63).

Table 8: Overview of the affordances in the top-level theme „Data"

Sub-Level 1 Theme	Affordance	Description	Exemplary publications
Data Acquisition	Multi-Source Data Acquisistion (27, +)	Gathering of data from multiple heterogeneous sources, of varying quality, volume and data kind.	Hassan et al. (2020), W. Zhang et al. (2017), Du et al. (2020), Hussain and Beg (2019)
	Multi-Source Information Acquisition (1, o)	Contextualising and categorising data for information acquisition.	Constantinescu and Vladoiu (2020)
	Multi-Source Knowledge Acquisition (1, o)	Extraction of knowledge from multiple sources of information and data.	Constantinescu and Vladoiu (2020)
	Real-Time Data Acquisition (11, o)	Continuous receiving and monitoring of data, as opposed to gathering data in acquisition intervals.	Rampérez et al. (2018), Ilyas et al. (2022), Dar et al. (2018), Cha et al. (2018)
Data Processing	Computing Capabilities (26, o)	General affording of computing power by FNs, to aid cloud data centers in computation and overcome hardware limitations of edge devices.	Khumalo et al. (2019), Jalowiczor et al. (2021), Muneeb et al. (2021), Hassan et al. (2020)
	Computing Capabilities in Close Vicinity (39, o)	Affording computing power by FNs that are placed near edge devices or at the FSs edge.	C. Zhu et al. (2022), Zheng et al. (2020), Cao et al. (2019), P. Wang et al. (2018)
	Distributed Computation (1, o)	Computation is afforded in a distributed way, to ease load on single FNs.	W. Zhang et al. (2017)
	Dynamic Load Balancing (1, o)	Load balancing can be performed dynamically.	X. Zhu et al. (2015)
	Load Balancing (4, o)	FSs can balance the load between a pool of available FNs and balance the load of cloud and fog layer.	Ilyas et al. (2022), S. Singh et al. (2016), Chouikhi et al. (2019), Fan et al. (2018)
	Optimized Information Granularity (1, o)	The granilarity of information analysis can be adapted based on service requirements (e.g. service level, real-time requirements).	Cao et al. (2019)
	Preprocessing (31, o)	Data from edge devices is partially processed, filtered or aggregated, before being sent back to edge devices or to higher hierarchy levels.	Wei and Wu (2019), W. Chen et al. (2019), Tsipis et al. (2020), Beri et al. (2022)
	Task Processing (28, o)	Calculation of entire tasks or service requests by FNs, potentially in a devide and conquer manner.	Liu et al. (2017), Muneeb et al. (2021), Cao et al. (2019), Rampérez et al. (2018)
Data Storage	Distributed Storage (1, o)	Affording of storage in a distributed manner, to ease storage load against one FN.	W. Zhang et al. (2017)
	Storage Capabilities (19, o)	Affording of data storage in between the end devices and cloud data centers. May involve the caching of data at FNs.	Mai (2019), Cao et al. (2019), Alghamdi et al. (2019), Soua and Tohme (2018),
	Storage Capabilities in Close Vicinity (28, o)	Affording data storage near edge devices at the edge of the FS.	J. Zhu et al. (2013), Alghamdi et al. (2019), Soua and Tohme (2018), Wei and Wu (2019)
Data Transmission	Customized Content Disctribution (1, o)	Distribution of content can be customized depending on the level of service.	Cao et al. (2019)
	High-efficiency Data Transmission (1, o)	Transmission of data in FSs is highly efficient.	C. Zhu et al. (2022)
	High-quality Data Transmission (1, o)	Data can be kept at a higher quality of transmission via a FS.	C. Zhu et al. (2022)
	Multi-Path Data Transmission (1, o)	FC affords the possibility of using different paths for data transmission in case of network congestion.	W. Zhang et al. (2017)
	Data Reduction for Transmission (7, +)	Reduction of size of data for transmission and redundancy of analysis data at the cloud level.	Chouikhi et al. (2019), Muneeb et al. (2021), Huang et al. (2017), Brzoza-Woch et al. (2016)
	Relay Nodes (16, 0)	Data and requests can be forwarded to the cloud or other FNs via relaying on FN level.	C. Zhu et al. (2022), Cao et al. (2019), S. Singh et al. (2016), Mekki et al. (2018)

Legend
Affordance: number = amount of publications the affordance was found in, o = argumentation only, + = empirical evidence

For example, in a medical setting, a single FN could be deployed at each hospital to gather the pain-monitoring data sent by multiple sensors within the respective hospital (Hassan et al., 2020, p. 8). The sensors from which the FNs receive the data may also be geospatially distributed (Hussain & Beg, 2019, p. 8). Combining the data from several sensors at the FNs can also be used to enhance the sensing capabilities of single entities (Du et al., 2020). In the VFC context intelligent vehicles may form a "cooperative sensing platoon" (Du et al., 2020, p. 10999) to enhance the sensing coverage of each vehicle even without externally installed FNs near the road, so called roadside units (RSUs), being available. This can be done by electing a head FN from FNs own ranks (Du et al., 2020, p. 10999). This can lead to more than 90% of the platoon's surroundings being within sensing coverage, eliminating dead zones within the platoon (Du et al., 2020, pp. 10999–11004).

Data acquiring can be performed in batches (e.g., data upload to the FNs every 15 minutes (S. Chang et al., 2020, p. 3)) or real-time (e.g., Rampérez et al. (2018, p. 4), Ilyas et al. (2022, p. 2), Cha et al. (2018, p. 9)). Such 'real-time data acquisition' is described as an affordance in 11 out of the 58 publications describing affordances. Real-time is thereby often not further specified, and, for example, spoken of as data being "continuously received, monitored and processed" (Dar et al., 2018, p. 2) or "streaming data" (Jaiswal et al., 2020, p. 3). Already one-second acquisition intervals are specified as only being near-real-time (Constantinescu & Vladoiu, 2020, p. 5). FC is reported to be more appropriate for real-time data elaboration than for batch processing (Battistoni et al., 2019, p. 164). However, even though data may be received in real-time, it not necessarily needs to be forwarded or made available via the cloud in real-time. For example, (pre-)processed real-time data can also only be forwarded in five-minute intervals (Beri et al., 2022, p. 7603).

The remaining two affordances for the sub-theme *data acquisition* are 'multi-source information acquisition' and 'multi-source information acquisition', both of which are only supported by one text-passage each from the same source, namely Constantinescu and Vladoiu (2020). A layered information retrieval process to first gather data from various sources (multi-source data acquisition), then contextualize, categorize, and condense information (multi-source information acquisition), and extract knowledge from multiple information and data sources (multi-source knowledge acquisition) on top of that is described (Constantinescu & Vladoiu, 2020, pp. 4–5). This example shows that FC can provide more data-related affordances than just mere *data acquisition*.

The gathered data can also be processed, which is captured by the *data processing* sub-theme. FC provides 'computing capabilities'. These may be used, for example, for preprocessing or the processing of entire tasks. FNs may aid cloud data centers in computation (see e.g., Khumalo et al. (2019), Jalowiczor et al. (2021), Beri et al. (2022)). Therefore, FNs may incorporate activities that are usually performed by the cloud server. For example, architectures may have the FNs include functions from network and application servers (Jalowiczor et al., 2021). FNs may also be part of a blockchain (e.g., Hewa et al. (2022), Tahmasebi et al. (2020)) and compute smart contracts (Hewa et al., 2022, p. 7178).

FNs at different hierarchical levels can be equipped differently in terms of computing power, with FN at the edge of the network providing fewer computing capabilities, whereas FN at higher hierarchical levels may provide extensive computing capabilities for data processing and analysis (Khumalo et al., 2019, p. 4). However, compared to the cloud, FNs are still restricted in terms of computing capabilities (Muneeb et al., 2021, p. 4). Depending on the computational power a service or task needs it can be offloaded to different FNs (e.g., Mai (2019), Alam et al. (2021)) to not consume too much energy (Mai, 2019, pp. 5–6). For doing so FNs may contribute some of their resources to interconnect with nearby FNs (Hassan et al., 2020, p. 7). By providing computing capabilities, FC offers a way to overcome hardware limitations for the end users' devices (Muneeb et al., 2021, p. 5).

Those computing capabilities are often describes as being near to the end devices (e.g., C. Zhu et al. (2022, p. 29), X. Zhu et al. (2015, p. 214), Zheng et al. (2020, pp. 41–42), Cha et al. (2018, p. 9), or Soua and Tohme (2018, p. 7)) or as residing at the edge (e.g., X. Zhu et al. (2015, p. 220), Karagiannis and Schulte (2020, p. 21), Cao et al. (2019, p. 167), P. Wang et al. (2018, p. 88)) affording 'computing capabilities in close vicinity' to the end users. These computing capabilities are in "range for single-hop communication" (C. Zhu et al., 2022, p. 26). Near proximity does, however, not necessarily mean "near" in the sense of distance. For example, in an architecture for usage in space (Cao et al., 2019), FC provides a space-based edge cloud and fog satellites, which are not necessarily near to the end devices (in space, e.g., satellites) by raw distance, but still nearer than any ground-based cloud data center. The FNs placed closest to the edge may be especially limited in computing resources, restricting the possible services to those not in need of resource-demanding processing (Karagiannis & Schulte, 2020, p. 21).

FC, furthermore, provides 'distributed computation' and '(dynamic) load balancing'. Like this, FSs can balance the load (dynamically) between a pool of available machines and FNs if the FN the service is requested from cannot process it locally (Ilyas et al., 2022, pp. 2-3, 8; S. Singh et al., 2016, pp. 732–733). In the case one FN is overwhelmed with service requests, requests and tasks can be offloaded to nearby FNs to aid in computation (W. Zhang et al., 2017, p. 63). Hereby the fairness of the system is important. The load needs to be balanced fairly between nodes, by loading more applications on FNs with higher computational power, and less to FNs with fewer capacity (Chouikhi et al., 2019, p. 1819). FC also allows for 'optimized information granularity' for the data processing depending on the service level (Cao et al., 2019, p. 168).

As already mentioned before, FC computing capabilities can be used for 'task processing' and 'preprocessing'. In the case of preprocessing data that is coming from the local edge devices, is partially processed, filtered, or aggregated before being sent back to the edge devices or to upper layer FNs or the cloud level for further processing or persistence (e.g., Wei and Wu (2019, pp. 615-616, 619), W. Chen et al. (2019, pp. 3–4), Tsipis et al. (2020, pp. 190–191), Cao et al. (2019, pp. 168–169)). The preprocessing step can also be used to determine the relevance of the data for the system or services (e.g., Mihai et al. (2018, pp. 744–746), Beri et al. (2022, pp. 7599–7601)) to later decide how to proceed with the data. Like this, for example, immediate reports to end devices of patients and healthcare professionals are possible, in case the FNs detect critical health conditions, whereas otherwise the data is sent to the cloud for further analysis and standard health recommendations (Beri et al., 2022, pp. 7599–7601). In contrast to preprocessing, task processing is concerned with calculating entire tasks or service requests posed at a FN. This may, however, include simple processing tasks submitted by other nodes in a divide and conquer manner (e.g., Liu et al. (2017, p. 25447), Muneeb et al. (2021, p. 5)), which in turn may be part of the submitting FN's data preprocessing. FNs build a fast service cluster by accepting tasks for processing from other FNs (Cao et al., 2019, p. 167). Task offloading can also be done by the edge devices, which may only have limited processing power (see e.g. Cao et al. (2019, p. 167), Soua and Tohme (2018, p. 7)) or from elected head FN to regular FNs (Du et al., 2020, p. 11001). The advantage of FC here is the possibility to immediately process tasks and take decisions at the FNs instead of submitting the data to a cloud data center and waiting for the results and decision to be made there (Ji et al., 2020, p. 55). Task processing of the data a FN receives may be the sole purpose of a FN (e.g., for the local anomaly detection in gas pipelines (Rampérez et al., 2018, pp. 4, 6, 12)). FC layers may also be used to train ML models and pass trained models to end devices and the data and analysis results to the cloud (Jaiswal et al., 2020, p. 3).

Besides *data acquisition* and *data processing* FC affords *data storage*. FC provides 'storage capabilities' somewhere in between the end devices and cloud data centers (Mai, 2019, pp. 2-3, 8). Similar to the computing capabilities provided, storage capabilities provided in higher levels of a FC architecture may be larger than those provided at the edge (Cao et al., 2019, p. 167). A common use case for storage capabilities is to provide data caching (e.g., Alghamdi et al. (2019, p. 5), Soua and Tohme (2018, p. 6)). This is especially relevant for FC affording 'storage capabilities in close vicinity' to the local devices at the edge. At such FNs intelligent caching of frequently requested contents can take place (e.g., J. Zhu et al. (2013, pp. 322–323), Alghamdi et al. (2019, p. 5)) or data that shall be uploaded to the cloud may be temporarily stored until the upload is finished (Wei & Wu, 2019, pp. 616, 618-619). Again, near proximity does not necessarily mean "near" in distance (e.g., Cao et al. (2019)).

Finally, FC provides *data transmission*. FC is described to afford 'high efficiency data transmission' and 'high-quality data transmission' (C. Zhu et al., 2022, p. 33). FC further "allows for customized [content] distribution of different information products according to different service levels" (Cao et al., 2019, p. 169) and provides the possibility of using different paths for data transmission (W. Zhang et al., 2017, p. 63).

FC further affords 'data reduction for transmission' and 'relay nodes'. By means of preprocessing the data before transmission (S. Chang et al., 2020, p. 4; Huang et al., 2017, p. 107; Muneeb et al., 2021, pp. 3–4), the size of the exchanged data can be reduced (Chouikhi et al., 2019, pp. 1817, 1820; Muneeb et al., 2021, pp. 3-4, 9) and data redundancy at cloud level can be reduced (Brzoza-Woch et al., 2016, p. 2). If the FC affordance relay nodes is used, data or requests FNs receive is forwarded to the cloud. This is done, for example, in a maritime scenario (C. Zhu et al., 2022), or in space-based FC (Cao et al., 2019, pp. 167–169). Furthermore, the relay nodes affordance is necessary, when the selected FN cannot provide the requested service (S. Singh et al., 2016, pp. 732–733), or to relay data between two clients (Mekki et al., 2018, pp. 3–4). Sometimes, specific FNs are selected as gateways and primarily perform relay-functionality (e.g., (Mekki et al., 2018, p. 3)).

Theme AT2: Network

FC provides 11 “Network” affordances. I find affordances in the sub-themes *communication*, *network organization*, and *network properties*. Table 9 provides an overview of all affordances grouped under the top-level theme “Network” in their respective sub-themes, with a short description, an indication of their validation status (o/+) in the used text extracts, and up to four exemplary publications in which the affordance is described.

Table 9: Overview of the affordances in the top-level theme „Network“

Sub-Level 1 Theme	Sub-Level 2 Theme	Affordance	Description	Exemplary Publications
Communication	Mobility	Mobile Communications (1, o)	FC allows edge devices to complete their requests completely under mobile connections.	S. Singh et al. (2016)
		Mobility Support (4, o)	FC supports serving mobile edge devices roaming between FNs without interruption.	W. Zhang et al. (2017), X. Zhu et al. (2015), Santos et al. (2021), Cha et al. (2018)
	-	Communication Capabilities (5, o)	Affording communication capabilities by FNs acting as fast short-range communication hubs.	Mai (2019), Du et al. (2020), Soua and Tohme (2018), Mayer et al. (2021)
		Network Connection (12, o)	Affording internet or cloud connection for edge devices.	Khumalo et al. (2019), Jalowiczor et al. (2021), Fan et al. (2018), Alghamdi et al. (2019)
		Offline Connectivity (1, o)	FC affords offline connectivity for critical services even when no internet connection is possible.	Alam et al. (2021)
Network Organization		Clear Network Organization (1, o)	FS networks have a clear organization with the possibility for coordinator nodes.	W. Zhang et al. (2017)
		Decentralization (6, o)	FNs are deployed in a decentral network, working independently from one another.	W. Chen et al. (2019), Silva et al. (2019), Ji et al. (2020), Hewa et al. (2022)
		Openness (2, o)	FC networks are open, as they allow for communication in and out of the system network in various ways.	W. Zhang et al. (2017), Rampérez et al. (2018)
Network Properties	Bandwith	High Bandwidth Connection (4, o)	FC networks afford high capacity bandwidth connections.	Ji et al. (2020), Mai (2019), Nurnoby and Helmy (2023), S. Singh et al. (2016)
		Saves Bandwidth (18, +)	FC usage saves bandwidth and provides networks with less congestion and traffic bottlenecks.	Ilyas et al. (2022), Hassan et al. (2020), Cha et al. (2018), X. Zhu et al. (2015)
	Latency	Low Latency (42, +)	FC affords low latency computation and communication networks.	Ji et al. (2020), Alghamdi et al. (2019), Tsipis et al. (2020), Knebel et al. (2021)

Legend
Affordance: number = amount of publications the affordance was found in, o = argumentation only, + = empirical evidence

The *communication* sub-theme is concerned with affordances related to network connection and end device *mobility*. FC affords 'communication capabilities' within the fog layer and for end devices. For example, in VFC, intelligent vehicles offering communication capabilities can be organized as FNs in a vehicular fog (Du et al., 2020, p. 10999). Further, long-journey vehicles, such as buses, taxis can be used as communication hubs offering short-ranged and fast communication (Soua & Tohme, 2018, pp. 2–4, 7). FSs may provide communication capabilities for end devices or be responsible for communication protocols (Mayer et al., 2021, p. 122728).

Furthermore, FC, can be used to afford end devices with a 'network connection' (to the cloud or general world wide web (internet connection)) on an on-demand and per device basis (Khumalo et al., 2019, p. 3). Due to the hierarchical nature of most FC architectures, a network connection is not necessary for every FN. Depending on the architecture, a network connection is only necessary for the highest-level FN (Jalowiczor et al., 2021, p. 6), as only this node takes care of communication with the cloud. Remote areas can be provided with computing services (Fan et al., 2018, p. 5) or internet access (Alghamdi et al., 2019, p. 5), even without edge devices being connected to the internet on their own.

FC further allows *mobility* affordances. It provides 'mobile communications' (S. Singh et al., 2016, p. 732) and affords 'mobility support' to hand over services from one FN to another without interruption in case the end devices using the service move from the proximity of one FN to another. Such mobility support is especially useful for, for example, video streaming use cases, in which a client can be served with their video without interruption, due to the FS taking care of handing over services between FNs, by already buffering the next few seconds of video at potential target FNs once the end device is detected to roam towards them to continue streaming the video from the exact position in time where the former FN stopped providing services (X. Zhu et al., 2015, pp. 207–208).

FC affords 'clear network organization', 'decentralization', and 'openness' in terms of *network organization*. Openness describes that the system allows for communication in and out of the system in various access ways (W. Zhang et al., 2017, p. 61). New entities can be added to the network by either the users themselves, or organizational agents, such as governments or service providers. Standard data models and application programming interfaces can be used to achieve openness (Rampérez et al., 2018, pp. 6, 12).

FC provides actors with decentralization. FNs included in the network work in a decentral way, by working on their own subtasks independently of one another and sharing necessary information (W. Chen et al., 2019, p. 3). Decentralization is inherently important for deploying blockchain peers via a FS (e.g., Silva et al. (2019, p. 13)).

Furthermore, FC is reported to provide a clear network organization, with the possibility of having a coordinator server (W. Zhang et al., 2017, pp. 61–62). In this case, edge devices are assigned to the closest FN by default but can be reassigned to other nodes if necessary or beneficial for system performance.

In terms of *network properties*, *bandwidth* and *latency* affordances could be identified.

A FS allows for ‘high bandwidth connection’ (Ji et al., 2020, p. 53; Mai, 2019, p. 2; Nurnoby & Helmy, 2023, p. 1105; S. Singh et al., 2016, p. 732) and ‘saves bandwidth’. High bandwidth connection can, for example, be established via wireless fidelity (WiFi) or 5G mobile connections (Ji et al., 2020, p. 53). Especially bandwidth savings are extensively discussed and empirically validated in several articles (e.g., Ilyas et al. (2022), Hassan et al. (2020), Cha et al. (2018)). Bandwidth can be saved, for example, by not serving multiple clients with the same content (e.g., videos) independently from one another, but providing a version of the video to a FN in their proximity and then serve clients interested in the range of the FN from there (X. Zhu et al., 2015, p. 210). Via reducing network usage towards the cloud, network congestion and traffic bottlenecks can be mitigated (Tsipis et al., 2020, p. 181) and, for example, in space-based FC, precious satellite-ground transmission bandwidth can be saved (Cao et al., 2019, p. 167). Validations performed reveal, that, for example, in healthcare FC architectures can improve network usage by 20-25% (Ilyas et al., 2022, p. 7), and that in contrast to CC being deployed in an IoT setting, the network load does not increase significantly when using a FS when the number of connected devices rises (Muneeb et al., 2021, p. 9).

Another frequently discussed FC affordance is ‘low latency’. 42 out of the 58 reviewed articles make according statements. FC provides low latency computation and communication to the end devices the services are expected at, as unnecessary and redundant communication and computation are resolved (Ji et al., 2020, p. 55). This especially shines, when the system load increases or more end devices are attached, as FC latency only slowly increases (e.g., Alghamdi et al. (2019, pp. 8–9), Hewa et al. (2022, pp. 7181–7182), Silva et al. (2019, p. 12), Hassan et al. (2020, pp. 17–18)). The more tasks are offloaded from the cloud to the FNs the lower is the resulting delay when fulfilling the task requests (Tsipis et al., 2020, p. 197). FC architectures are reported to generally have lower latency than CC architectures multiple times (e.g., Mai (2019, p. 4), which is supported by several articles including evidence for this affordance (e.g. Tsipis et al. (2020, p. 197), Alghamdi et al. (2019, p. 9), Knebel et al. (2021, pp. 6–7), Cha et al. (2018, pp. 13–15)). For example, the average message time can be reduced by up to 64% for digital twins, when using FC compared to a cloud-only setting (Knebel et al., 2021, p. 7) and general transmission delay is experimentally shown to be up to seven times higher for cloud-based content delivery networks with up to 100 end devices connected (Alghamdi et al., 2019, p. 9).

Theme AT3: Fog System “Properties“

The third theme identified is “Fog System Properties”. This theme comprises of affordances that can be seen as properties the FS in its entirety provides to potential end users, such as organizations. The theme encompasses six sub-themes. An overview of these and the affordances grouped therein can be obtained from Table 10, alongside a short description of each affordance and up to four exemplary publications that were found to report the affordance, as well as a short indication of the validation status (o/+) in the used text extracts.

Table 10: Overview of the affordances in the top-level theme „Fog System Properties"

Sub-Level 1 Theme	Sub-Level 2 Theme	Affordance	Description	Exemplary Publications
Autonomy & Management	Autonomy	Autonomous Decisions (13, o)	FNs in a FS can make autonomous decsions without relying on the cloud (e.g. area level decisions).	Huang et al. (2017), Mekki et al. (2018), W. Zhang et al. (2017), Tsipis et al. (2020)
		Autonomous Management (2, o)	FNs organized in a FS autonomously manage their services and data.	H. Zhang et al. (2020), W. Zhang et al. (2017)
		Autonomy (1, o)	FSs can be deployed using self-sustained FNs.	Brzoza-Woch et al. (2016)
	Management	Manageability (4, o)	FSs' FNs can be centrally inventorized, set up, and updated or managed by head FNs.	Battistoni et al. (2019), Du et al. (2020), Vega et al. (2018), Soua and Tohme (2018)
Contextuality & Locality		Context-awareness (4, o)	FSs can take decisions depending on the situation they are in and the context of deployed FNs.	Rampérez et al. (2018), Brzoza-Woch et al. (2016), Cerina et al. (2017), J. Zhu et al. (2013)
		Edge Location (1, o)	FSs afford rich services a the edge of the network.	X. Zhu et al. (2015)
		Information-Leveraging (8, o)	FSs make use of information readily available in the network to provide services in the best possible way.	X. Zhu et al. (2015), Hernández-Nieves et al. (2020), Chun et al. (2016), J. Zhu et al. (2013)
		Locality (27, o)	FSs afford services, data, and processing local at the level of FNs.	P. Wang et al. (2018), Brzoza-Woch et al. (2016), Ilyas et al. (2022), Tsipis et al. (2020)
		Location-awareness (19, o)	FSs are aware of the location of end users and FNs in the system and can make use of that in service provisioning.	Dar et al. (2018), H. Zhang et al. (2020), Constantinescu and Vladoiu (2020), (Mirzaie et al., 2021)
Distributed System	Distribution	Geographical Distribution (15, o)	FSs are geographically distributed, potentially covering large areas with FNs.	Chun et al. (2016), Battistoni et al. (2019), Fan et al. (2018), Vega et al. (2018)
		Scalability (9, +)	FSs are scalable on edge and fog level.	Tsipis et al. (2020), Battistoni et al. (2019), Cerina et al. (2017), Soua and Tohme (2018)
	Fault Tolerance	Fault Tolerance (2, o)	FSs are fault tolerant with regard to FN failure.	Muneeb et al. (2021), Maheswaran et al. (2019)
		Replication (1, o)	FSs afford replication of data to nearby FNs.	Silva et al. (2019)
Flexibility, Adaptability, Interoperabiltiy	Heterogenity	Federation (1, o)	FSs afford federation of services across domains.	X. Zhu et al. (2015)
		Heterogeneity (6, o)	FSs are composed of heterogeneous components on fog and edge level, and can cope with this.	Battistoni et al. (2019), Khumalo et al. (2019), Brzoza-Woch et al. (2016), Ji et al. (2020)
	-	Adaptability (1, o)	FSs are adaptable.	Constantinescu and Vladoiu (2020)
		Flexibility (1, o)	FSs provide service flexibility.	H. Zhang et al. (2020)
		Interoperability (8, o)	Services, providers and system components are interoperable with one another.	Vega et al. (2018), Constantinescu and Vladoiu (2020), Silva et al. (2019), Hassan et al. (2020)
Low Energy & Cost	Energy	Low Energy Consumption (5, +)	FSs have low overall energy consumption.	Hussain and Beg (2019), Ji et al. (2020), Tsipis et al. (2020), Cerina et al. (2017)
	Low Cost	Low Cost Devices (4, o)	FSs can be built using low cost devices.	Tsipis et al. (2020), Brzoza-Woch et al. (2016), Battistoni et al. (2019), Dar et al. (2018)
		Low Execution Cost (1, +)	FSs have low cost of execution.	Hassan et al. (2020)
		Low Transmission Cost (1, o)	FSs have low cost of data transmission.	Luo et al. (2021)

Sub-Level 1 Theme	Sub-Level 2 Theme	Affordance	Description	Exemplary Publications
Privacy, Safety & Security	-	Privacy (6, o)	FSs provide privacy to users using their services or storing their data at FNs.	Jalowiczor et al. (2021), Silva et al. (2019), Beri et al. (2022), Vega et al. (2018)
		Safety (1, o)	FSs afford safety.	Constantinescu and Vladoiu (2020)
	Security	Security (10, o)	FSs afford security.	Mai (2019), H. Zhang et al. (2020), W. Chen et al. (2019), Tsipis et al. (2020)
		Access Validation (3, +)	FSs can perform access validation for data retrieval and data processing on the fog level.	Silva et al. (2019), Vega et al. (2018), Beri et al. (2022)
Legend Affordance: number = amount of publications the affordance was found in, o = argumentation only, + = empirical evidence				

FC provides affordances in the area *autonomy and management*. *Autonomy* affordances are about self-sustainability and independence from the cloud for decision-making. FNs and devices can make ‘autonomous decisions’ based on the information gathered on their own without relying on the cloud or other FNs to make the decision for them. Decisions FNs may make on their own as a fog layer may be area-level decisions (Huang et al., 2017, p. 106). The capability of making autonomous decisions is especially useful in scenarios, such as disaster management (e.g., Mekki et al. (2018, p. 4)), as in the case of a disastrous event the connection to the cloud may not be possible, decision-making and data retrieval from the nodes, however, may be necessary.

In similar situations another FC affordance may come into play, ‘autonomy’. Autonomy describes to possibility to equip FNs in a way that allows for complete autonomy in terms of power supply, by relying on renewable energy and power storage (Brzoza-Woch et al., 2016, pp. 2–3), so that FNs maintain operable if power is cut or during blackout periods.

FC can further afford ‘autonomous management’ as they autonomously manage their services and data even though being potentially controlled by a (local) coordinator (H. Zhang et al., 2020, p. 659; W. Zhang et al., 2017, pp. 61–62). FC provides the *management* affordance ‘manageability’, by enabling for centralized inventory, setup, and update possibilities (Battistoni et al., 2019, p. 164) or management by the local head FN (Du et al., 2020, p. 10999).

Furthermore, FC provides affordances connected to *contextuality and locality*. ‘Context-awareness’ and ‘location-awareness’ are both described as essential FC characteristics by Iorga et al. (2018, pp. 3–4) and could be retrieved as affordances in the literature review as to be expected. FNs know the situation, as well as the location they are used in and can thus optimize data routing and quality (e.g., J. Zhu et al. (2013, pp. 322–323)). Moreover, FNs can make decisions based on the location (e.g., alert the closest hospital available in case of an emergency (Dar et al., 2018, p. 2) and data traffic that is usually found at their location (e.g. to detect denial of service attacks (H. Zhang et al., 2020, p. 659). The data stored at the FNs often has local relevance (e.g., Constantinescu and Vladoiu (2020, pp. 3–5), Mirzaie et al. (2021, p. 594)) and the FNs are aware of other entities in the system that may be in need of these data. Like this, for example pipeline actuators can be notified about the gas pressure in order to close valves and cut off sections of a pipeline if necessary (Rampérez et al., 2018, p. 6). As FNs are location- and context-aware, FN of other domains at the same location can be notified, to for example reroute road traffic to make sure traffic does not flow though locations with too high gas pressure. Context-awareness can also manifest in changed FN behavior depending on the current FN context. For example, FNs deployed for flood detection at a levee, that normally upload data to the cloud once a day can decide to upload data every 15 minutes in case of flood threat to keep the data available to other agents near-real-time due to potentially rapidly changing situations (Brzoza-Woch et al., 2016, p. 3). Closely related to both these affordances, FC may provide 'information-leveraging' to organizations. FSs can use information that is readily available in the network, such as the usage information about the wireless connection of a mobile end user, which can be used to derive their potential roaming path (X. Zhu et al., 2015, p. 206) or use information gathered about the end device itself to choose the best parameters for service provision (e.g., the video quality best suited to serve a mobile client (X. Zhu et al., 2015, p. 216). Moreover, user preferences and can be stored to be available for further services (Hernández-Nieves et al., 2020, pp. 6–7).

'Locality' on the other hand, is concerned with the FS's property to provide locally available services, resources, and data or to process tasks locally. Like this, face recognition can be performed locally with users facial features stored on the edge devices (P. Wang et al., 2018, p. 89). Especially in disaster management, locality is important, as FNs, for example, can still assess the local threat level (Brzoza-Woch et al., 2016, p. 2) and provide it to, for example, residents and rescue teams. The decision to keep data locally for processing or to offload it to the cloud can be made by the FNs themselves, based on different parameters (e.g., criticality of the data in a medical setting (Ilyas et al., 2022, p. 7), offloading percentage parameter (Tsipis et al., 2020, p. 193)).

Another essential fog computing characteristic is 'scalability' (Iorga et al., 2018, pp. 3–4). This work retrieves scalability as a FC affordance placed in the *distributed system* sub-theme. FSs provide scalability by increasing/decreasing the number of sensors (e.g., Tsipis et al. (2020, p. 182)) or FNs, either horizontally (more FN on the same level) or vertically (more levels of FN in the fog layer) (Battistoni et al., 2019, p. 164; Cerina et al., 2017, p. 5). FSs are described to be geographically distributed to serve users at the edge of the network (see e.g., Chun et al. (2016, pp. 91–93), Battistoni et al. (2019, p. 164)), by scattering FNs across different geographical locations to grasp the data in their respective region (Fan et al., 2018, p. 4). This is covered by the 'geographical distribution' affordance, showing another essential FC characteristic. It is deemed one of the most important FC characteristics (Battistoni et al., 2019, p. 164). This distribution is also key for use cases in which blockchain peers shall be deployed on the FNs (e.g., (Vega et al., 2018)). Grouped under the level-2-theme *fault tolerance* I further find that embracing the distributed nature of FSs, 'replication' of data to nearby FNs allows for better 'fault tolerance' and data availability (Silva et al., 2019, p. 6). Fault tolerance can further be provided as an affordance by the possibility of mitigating FN failure by transferring services to other FNs in the vicinity (Muneeb et al., 2021, pp. 4–5)) and by having several FNs whose service areas overlap (Maheswaran et al., 2019, p. 4).

The TA reveals another level-1-theme, namely *flexibility, adaptability, and interoperability*. FSs provide ‘adaptability’ (Constantinescu & Vladoiu, 2020, p. 5), and ‘interoperability’ of services, providers, and system components, by relying on interoperable data models (Vega et al., 2018, p. 3). Furthermore, ‘flexibility’ affords the possibility to host services for specific uses, such as security operations, that are independent from business processes and thus provide more flexibility (H. Zhang et al., 2020, p. 659). Looking at *heterogeneity* I can find that FS can be used for the ‘federation’ of services across domains (X. Zhu et al., 2015, p. 205), and provides ‘heterogeneity’. FNs themselves are heterogeneous in terms of computing power and storage capabilities (Battistoni et al., 2019, p. 164; Khumalo et al., 2019, p. 4) and they can cope with heterogeneous end devices, sensors (Brzoza-Woch et al., 2016, p. 2), and connections effectively (Ji et al., 2020, p. 53). Even though interoperability, federation and heterogeneity are among the essential FC characteristics, the literature support for the respective affordances is surprisingly low. However, the theme as a whole is well supported and provides a coherent point of view on specific FC affordances.

The theme *low energy and cost* deals with FC’s energy consumption and the cost of employing a FS. ‘Low energy consumption’ describes that FSs consist of components that on its own have low energy consumption. FSs are shown to consume more than 44% less energy than cloud systems in the same setting (Hussain & Beg, 2019, p. 21). But not only the energy consumption of the employed devices is lower than in CC, also the energy consumption that is used for data transmission is decreased by using FC as FC affords data preprocessing and performs a reduction of data for transmission (S. Chang et al., 2020, p. 4). Cost-wise, the FC affordances, ‘low execution cost’ (empirically validated in Hassan et al. (2020, pp. 14–15)), and ‘low transmission cost’ due to *data processing* at the FNs (Luo et al., 2021, p. 251), and ‘low cost devices’ could be identified. FS consist of components that are less expansive and smaller than building a data center, whilst still offering similar services (Tsipis et al., 2020, p. 181). Low cost devices were especially highlighted in articles concerning small/medium sized businesses (e.g., olive growers (Tsipis et al., 2020)) or municipal endeavors (e.g., flood detection in disaster management (Brzoza-Woch et al., 2016)).

As the last “Fog System Properties” sub-theme I identify *privacy, safety, and security*. This sub-theme collates the affordances ‘privacy’, ‘safety’, ‘access validation’, and ‘security’. Privacy can be afforded, by only sharign information that is necessary for other services with the environment and not all information (Jalowiczor et al., 2021, pp. 10–11). Moreover, end users may decide, which services can access their data stored in the system (e.g., (Silva et al., 2019, pp. 5-6. 13)). Like this, for example, patients can choose, which stakeholders may access which subset of their medical data by using a blockchain. Such access validation is not only related to data retrieval, but also to data processing. For example, in architecture for medical data analysis of pregnant women, the sensor data received is only processed if access validation and identity check via biomarkers (iris and face recognition) are positive, otherwise, it is discarded to ensure that only data from the correct individual are processed (Beri et al., 2022). FSs can also log the access to and usage of data (Vega et al., 2018, p. 4). Furthermore, FC can provide security. FNs allow for deploying “heavier” security algorithms at the edge of the network than possible with having IoT devices directly connected to the cloud (Mai, 2019, p. 7). FNs can also be used to set up encrypted communication channels (H. Zhang et al., 2020, p. 659). FSs are also reported to afford safety (Constantinescu & Vladoiu, 2020, p. 5), which is, however, not well supported by the literature reviewed, as only one paper mentions safety as an affordance.

Theme AT4: MISC Affordances

The last affordance theme is “MISC Affordances”. This theme comprises of affordances that could not be fit into any other theme and are thus considered miscellaneous. The theme encompasses three affordances in a single sub-theme. An overview of the theme and the affordances grouped therein, alongside a description, an indicator for the status of their validation (o/+) in the text extracts used and the number of publications they were found in, can be obtained from Table 11.

Table 11: Overview of the affordances in the top-level theme „MISC Affordances“

Sub-Level 1 Theme	Affordance	Description	Exemplary Publications
Applications	Continuity of Services (1, o)	FC provides continuity of services to edge devices.	Nurnoby and Helmy (2023)
	Multiple-Application Support (3, o)	FC allows for several services beeing deployed on the same hardware platform.	Cao et al. (2019), Santos et al. (2021), Knebel et al. (2021)
	Service Migration (1, o)	FC allows for service migration.	X. Zhu et al. (2015)
Legend Affordance: number = amount of publications the affordance was found in, o = argumentation only, + = empirical evidence			

The *applications* sub-theme gathers affordances mentioned in the literature that are related to the applications or services FSs support. FC provides the possibility of ‘continuity of services’ even in the case of internet connection loss. This is deemed important for surveillance applications (Nurnoby & Helmy, 2023, p. 1105). FC, furthermore, provides ‘multiple-application support’. This affordance describes that FC supports employing several services on the same hardware platform. For example, in space technology traditional satellites do only support the functions they are built for, whereas fog satellites utilize virtualization technology to provide special services on a general platform that can easily be reconstructed, updated, and run isolated from each other (Cao et al., 2019, p. 168). FC further allows for ‘service migration’ (X. Zhu et al., 2015, p. 210). It should not go unmentioned, that the *application* affordances are not well supported in the reviewed literature. Moreover, all of them may be eligible to be merged with other affordances. More supporting literature and further discussion would be necessary for a decision on this.

4.1.2. Fog Computing Services

Out of the 58 articles included in the review, 56 described what services they are using FC for. Identified during the TA, three themes emerged from to codes. These three themes are the architectural service models, namely “IaaS”, “PaaS”, and “SaaS”, also described by Iorga et al. (2018, pp. 4–5). However, they were not primarily chosen as themes because of theoretical reasons, but for coming up during the coding process. These three themes include a total of 12 different service types, not including generic IaaS, PaaS, and SaaS as separate service types.

Figure 7 shows the thematic map of FC services that resulted from the TA based on the literature included in the review. As the top-level themes emerged from existing codes, they are displayed exactly like the 12 identified service types.

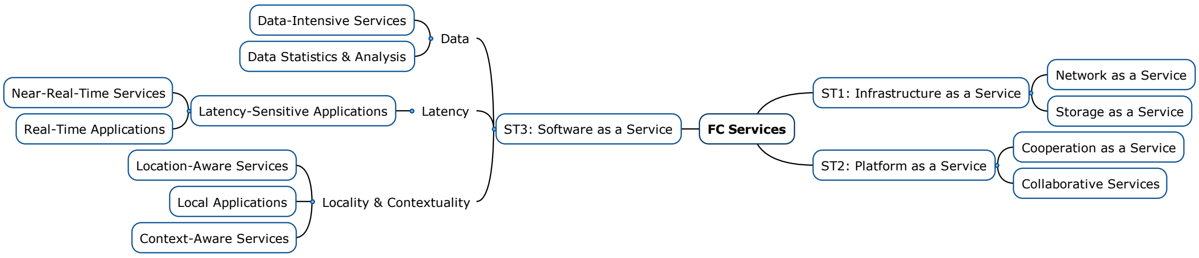


Figure 7: Thematic Map of FC services

Theme ST1: Infrastructure as a Service

The first service theme discussed in literature is “IaaS”. This theme encompasses the provisioning of hardware, such as memory, computing power, or storage and the management of these resources. IaaS in this general sense is described as a service type in Pecori (2018, p. 14). Two types of services were identified for the “IaaS” theme, ‘Network as a Service’ and ‘Storage as a Service’. Table 12 provides an overview of the theme and its services, with a description and up to four exemplary publications.

Table 12: Overview of the services in the top-level theme „Infrastructure as a Service”

Service	Description	Exemplary Publications
Network as a Service (5)	Provisioning of network as an infrastructure to edge devices for connection to the cloud or the internet.	Mekki et al. (2018), (Battistoni et al., 2019), Cha et al. (2018), Constantinescu and Vladoiu (2020)
Storage as a Service (2)	Provisioning of storage capabilites to clients and edge devices.	Cha et al. (2018), Constantinescu and Vladoiu (2020)
Legend Service: number = amount of publications the affordance was found in		

Network as a Service describes the provisioning of network infrastructure. For example, edge devices can use vehicular fogs as relay (Mekki et al., 2018, pp. 3–4). FNs connect edge devices with the internet or the cloud and provide Network as a Service (Battistoni et al., 2019, p. 162; Cha et al., 2018, pp. 8–9; Constantinescu & Vladoiu, 2020, p. 3; Ji et al., 2020, p. 54).

The second service-type in this theme is Storage as a Service (Cha et al., 2018, pp. 8–9; Constantinescu & Vladoiu, 2020, p. 3). FC can be used to provide storage to IoT devices or mobile users in near vicinity (Cha et al., 2018, pp. 8–9).

It is noteworthy, that even though IaaS in general also encompasses computing resources and input-/-output provided as a service (Pecori, 2018, p. 14). During the TA of the relevant literature, these types of services were not recovered. This may be due to only one researcher involved in the coding process and subjective bias. There are services described that incorporate these missing IaaS services and the already recovered ones, put under the SaaS theme, as not the IaaS service were in the focus of description, but the provided SaaS services. As SaaS incorporates infrastructure resources, that, however, are not managed by the organizations using FSs, but by the FS provider, this seems reasonable. Active co-coder discussion could alter the coding and lead to recovering the missing services or to more support for the existing ones, in the case that some of the text-passages that are currently discussed under SaaS affordances are more related to basic IaaS provisioning. In the end, subjective bias and a lack of discussion between different researchers is one of the limitations of this work (see section 5.3.).

Theme ST2: Platform as a Service

The second service theme identified during the TA is “PaaS”. PaaS is described as FSs providing services of data stream management, dynamic resource allocation and semi-permanent storage for a neighborhood of edge devices. Furthermore, PaaS services offer planning and execution services, decision-making opportunities or dispute solving for the SaaS layer. PaaS in this general sense is described as a service type in Pecori (2018, p. 14). Iorga et al. (2018, p. 5) refer to PaaS as a means to deploy (customer-created) applications on top of a cluster of federated FNs, without having the customer managing or controlling the underlying infrastructure. Two types of such services were identified for the “PaaS” theme, namely ‘Collaboration Services’ and ‘Cooperation as a Service’. Table 13 provides an overview of the theme and its services.

Table 13: Overview of the services in the top-level theme „Platform as a Service”

Service	Description	Exemplary Publications
Collaborative Services (3)	Provisioning of services provided by several FNs with a shared interest in the service outcome.	Fraga-Lamas et al. (2020), Cao et al. (2019), Soua and Tohme (2018)
Cooperation as a Service (3)	Provisioning of services by several FNs without shared interest in the service outcome.	Constantinescu and Vladoiu (2020), Du et al. (2020), Alghamdi et al. (2019)
Legend Service: number = amount of publications the affordance was found in		

FC enables for services that are processed and provided by several FNs with a shared interest in service outcome, so called collaborative services. In an industrial setting, FC, for example, enables FN that are physically distributed to collaborate and communicate with each other in order to provide their services (Fraga-Lamas et al., 2020, p. 45497). However, not only FNs may collaborate when providing services, but also entire application systems (e.g., a FS deployed in a space setting could enable "earth observation and multi-star data fusion" application systems to collaborate (Cao et al., 2019, p. 168)). Furthermore, collaboration between the different layers in a FS maximizes the utilities of the different layers (Soua & Tohme, 2018, p. 7).

Cooperation as a Service on the other hand describes services in which FNs do not collaborate in a shared interest but still cooperate in order for one of them to provide services. ‘Cooperation as a Service’ is foreseen for the field of VFC (Constantinescu & Vladoiu, 2020, p. 3). Also in VFC, a cooperative sensing platoon architecture enabled by FC is described (Du et al., 2020). But not only in VFC Cooperation as a Service can be found. In content delivery, architectures are possible, in which FNs cooperatively cache content and provide it to one another on request, so that each one of them can fulfill users content requests without cloud connection if possible (Alghamdi et al., 2019).

As already seen for the IaaS theme, the reviewed literature does not support PaaS on a wide scale. This may again be due to subjective coder bias or due to the fact, that most SaaS services also encompass PaaS without explicitly stating it, as the SaaS layer subsumes PaaS capabilities.

Theme ST3: Software as a Service

The last service theme identified in the reviewed literature is “SaaS”. The fog service customer can use the fog providers applications provided on a federated cluster of FNs, without managing the services or the underlying platform (Iorga et al., 2018, p. 5). This is also recovered in the literature, where SaaS encompasses big data and data stream mining/analysis, permanent storage and business intelligence, that is provided by powerful FNs (Pecori, 2018, p. 14). Most of the service types found during the TA are placed in the SaaS theme. A possible explanation for this phenomenon can be found for the smart grid domain (Hussain & Beg, 2019, p. 15). As the IoT resources are limited, the usage of SaaS on side of the fog service customer seems most feasible for smart grid environments, even though PaaS and IaaS are possible as well. The services grouped under “SaaS” are placed in three level-one sub-themes, *data-focused services*, *latency-focused services*, and *locality & contextuality-focused services*. Table 14 provides an overview of the level-one sub-theme for SaaS and their respective services, with a short description, number of publications the service was found in, and up to four exemplary publications.

The first SaaS level-one subtheme groups the *data-focused services* ‘data statistics and analysis’ and ‘data-intensive services’.

Data statistics and analysis describes that a FS can be used to provide statistical information about the data stored or processed within it (e.g., driver acceleration statistics or speed variations to enable driver assistance in a VFC setting (Constantinescu & Vladoiu, 2020, pp. 4–5). Also, user and IoT-profiles can be created based on the data and its analysis, to understand complex relationships through data analysis and learning (Ji et al., 2020, p. 54). Data statistics and analysis may be the sole service provided by the FS, for example, in a medical setting to detect patients pain based on analysis of the transmitted sensor data at the fog level (Hassan et al., 2020). However, the data extracted and analysis results can be used, for example, for further processing (Huang et al., 2017, p. 107; Mekki et al., 2018, p. 3). Such further processing may be data-intensive services relying on statistical data or learning results.

These data-intensive services require a lot of computational and/or storage capacities to deal with large amounts of data generated at lower hierarchy levels, especially the edge layer. Some of the services described for FSs in the literature would not be possible without the usage of FC. This is, for example, the case for high-quality video-based maritime applications like search and rescue at sea, as described by C. Zhu et al. (2022). In a non-FC setting, the video quality usually is reduced because of computing capacities and latency being limited, as well as high-cost satellite link connection to the land-based control center. A higher resolution of the captured and processed video directly transfers to higher data quality but also higher computing capabilities being necessary, which are now provided feasibly by FNs in the vicinity of the video capturing devices. Like this, only critical information, like the location of survivors can be, inferred from higher resolution video material an sent to the land-based control center via satellite links.

Table 14: Overview of the services in the top-level theme „Software as a Service”

Sub-Level 1 Theme	**Sub-Level 2 Theme**	**Service**	**Description**	**Exemplary Publications**
Data-focused Services		Data Statistics and Analysis (13)	Provision of statistical information about the data stored or processed as well as usage of entity profiles based thereon.	Constantinescu and Vladoiu (2020), Ji et al. (2020), Abdali et al. (2021), Huang et al. (2017)
		Data-intensive Services (25)	Provision of services that require a lot of computational and/or storage capabilities to handle large amounts of data.	C. Zhu et al. (2022), Mirzaie et al. (2021), Nadeem et al. (2019), W. Chen et al. (2019)
Latency-focused Services	-	Latency-sensitive Applications (21)	Provision of services sensitive to delay and latency.	C. Zhu et al. (2022), X. Zhu et al. (2015), Karagiannis and Schulte (2020)
	Latency-sensitive Applications	Near-real-time Services (3)	Provision of services performing in near-real time, for example, due to data aqcusition intervals.	Constantinescu and Vladoiu (2020), Beri et al. (2022), Tsipis et al. (2020)
		Real-time Applications (29)	Provision of services for real-time data processing or decision-making.	Battistoni et al. (2019), Luo et al. (2021), Fraga-Lamas et al. (2020), Hassan et al. (2020)
Locality & Contextuality-focused Services		Location-aware Services (11)	Provision of services taking into account the client’s and FN’s current location for the service provision.	C. Zhu et al. (2022), Maheswaran et al. (2019), Chun et al. (2016), Hussain and Beg (2019)
		Local Applications (16)	Provision of services that are not based on the cloud but handeled completely locally at the FNs.	Mekki et al. (2018), Brzoza-Woch et al. (2016), Fraga-Lamas et al. (2020), Muneeb et al. (2021)
		Context-aware Services (9)	Provision of services taking the current context of client and FN into account.	Mekki et al. (2018), Rampérez et al. (2018), C. Zhu et al. (2022), Chun et al. (2016)

Legend
Service: number = amount of publications the affordance was found in

But not only the data quality may make the usage of FC necessary. The high volume of information gathered by the multitude of IoT devices and sensors in for example smart city (e.g., Mirzaie et al. (2021, p. 595)) or VFC (e.g., Nadeem et al. (2019, p. 295)) use cases need to be somehow processed. FC provides a way to deal with this enormous amount of data and provide services based on that data. Furthermore, data of high volume can be served to multiple end users in the same area, for example, by saving a high-quality version of the video on the FNs and resend it to the end users (X. Zhu et al., 2015,

p. 209). Data marketplaces, as described by Vega et al. (2018) may prove helpful in sharing and gathering all the data necessary for such services.

FC, further, enables distributed computing as part of data-intensive services, that are not possible in the same way by solely relying on the cloud, as they include distributed and independent calculation and preprocessing by each FN (W. Chen et al., 2019, p. 3).

The second SaaS level-one sub-theme is named *latency-focused services* and deals with services that have stringent latency limitations, such as ‘latency-sensitive services’, ‘real-time applications’, and ‘near-real-time services’. The latter two are considered special kinds of latency-sensitive services, that are often mentioned and, thus, coded separately, to enable for a more fine-grained discussion of potential service-types.

In total, 21 papers discuss latency-sensitive applications, without necessarily describing them as (near-) real-time. FC can be used to provide such latency-sensitive applications (e.g., search and rescue at sea (C. Zhu et al., 2022), low-latency video streaming (X. Zhu et al., 2015), unmanned arial and ground vehicles (Ji et al., 2020), audio Search (W. Chen et al., 2019)). To do this, delay sensitive tasks are deployed on the FNs close to the edge devices to lower communication latency (Karagiannis & Schulte, 2020, p. 21). Services with less vulnerability to delay can be deployed on FNs distant to the edge devices (Karagiannis & Schulte, 2020, p. 21). Furthermore, service requirements can be used for service latency optimization (Cao et al., 2019, p. 168). Like this, services can be scattered across FNs to optimize latency for each service and end device.

In some settings cloud-based solutions are already in place and possible, but FSs outperform these (e.g., health applications (Silva et al., 2019, p. 12), industry applications (Mai, 2019, p. 8)) However, some latency-sensitive services are enabled by relying on FC, such as low latency search and rescue at sea (C. Zhu et al., 2022), and anomaly detection with low latency (Mirzaie et al., 2021). However, the discussion on enablement of novel applications or enhancement of cloud-based solutions by FC can be to some degree cut down to a discussion of the level of abstraction. For example, search and rescue at sea is possible without FC, but at high cost and latency, thus FC would only enhance a cloud-based solution. If the level of abstraction is changed to regarding low-latency search and rescue at sea, CC cannot provide this, and FC becomes an enabler for this application. The question on whether FC enables or enhances such (and other) types of services and applications and in which settings and on what level of abstraction needs to be investigated more closely by future research.

Real-time applications are latency-sensitive applications for which real-time processing of the data or real-time decision-making are reported. FC applications are reported to be more appropriate for real-time processing than for batch processing (Battistoni et al., 2019, p. 164). The literature discusses real-time applications for different sectors, such as real-time traffic flow control for smart cities (e.g., Luo et al. (2021), Huang et al. (2017), Cha et al. (2018)), real-time video transcoding (X. Zhu et al., 2015), real-time pipe monitoring in smart manufacturing (Fraga-Lamas et al., 2020) or the real-time monitoring of patients’ pain levels in medical settings (Hassan et al., 2020).

Real-time applications can be used for safety services, for example in the transportation sector, where driver and passenger safety may be provided by pervasive services, real-time vehicle status and diagnostics, and active on-road safety (Constantinescu & Vladoiu, 2020, p. 4). Especially monitoring services can benefit from being deployed on a FS, as the continuous performance of monitoring activities even in case of connection failure to the cloud is possible (Wei & Wu, 2019, p. 616).

Providing some real-time services, such as urban water anomaly detection (Mirzaie et al., 2021), is closely related to providing *data-focused services*, as a lot of sensor data is necessary and needs processing. Such real-time services are only possible in a real-time manner due to the hierarchical structure of FC architecture (Mirzaie et al., 2021, p. 593), which allows for "moving analytics to the source of the data" (Muneeb et al., 2021, p. 5). The real-time processing of received data can also be done depending on the criticality of the data (Ilyas et al., 2022, p. 6).

Less supported in the reviewed literature, but neither less important are near-real-time services. These are services that acquire and process data in acquisition intervals that may be close to real-time (e.g., 1-second interval for VFC (Constantinescu & Vladoiu, 2020, p. 5)). However, longer acquisition intervals are possible (e.g., 5-min acquisition intervals for pregnant women’s health status surveillance (Beri et al., 2022)). Like this, the incoming data can be monitored in a timely manner, which still allows for a close monitoring of, for example, olive groves in smart agriculture (Tsipis et al., 2020, p. 196). Near-real-time services are also considered to be “almost real-time“ (Tsipis et al., 2020, p. 198). Such a near-real-time monitoring FS is shown to outperform traditional CC-based monitoring in terms of throughput, average response time and system load (Tsipis et al., 2020, pp. 196–198), indicating that FC may enhance CC for such applications.

The last level-one sub-theme for “Software as a Service” is *locality and contextuality-focused services.* This theme is well supported in the literature as many articles mention services that are grouped within this sub-theme. The three services identified are ‘local applications’, ‘location-aware services’, and ‘context-aware services’.

FSs can host local applications that are neither provided by nor based on the cloud but are handled locally. This allows for services, even if the remote cloud is not available (e.g., due to natural disasters) and includes fog management services (Mekki et al., 2018, p. 4). Like this, localized flood risk assessment is possible in disaster management, even though communication channels may not be available, and rescue teams are enabled to access important local information in a rapid and reliable way and without the necessity of an internet connection (Brzoza-Woch et al., 2016, pp. 1, 4). FC may also be used to provide local ad-hoc services (e.g., in a smart manufacturing shipyard (Fraga-Lamas et al., 2020, p. 45497) or for providing locally cached data instances (e.g., in content delivery networks (Alghamdi et al., 2019)).

Local services may also be one step in the overall data processing, as data may be preprocessed by services provided by the FNs locally (Muneeb et al., 2021, p. 4). If services are available at multiple FNs, algorithms may choose to use the local service over those residing at non-local FNs (S. Singh et al., 2016, p. 733). FC, further, enables blockchain services near the end user, as the storage of blockchain nodes on IoT devices is not feasible due to these devices only having few resources capabilities (Tahmasebi et al., 2020, p. 8). FNs bring natural advantages for the operation of a blockchain (Zheng et al., 2020, p. 41). FNs are used as blockchain peers and store a local copy of the ledger. This, for example, allows for security-related operations (Hewa et al., 2022, pp. 7176–7178) or for building a distributed peer-to-peer data marketplace that data sellers and buyers can trust (see Vega et al. (2018)).

FC can be used to provide location-aware services, such as location-aware crowdsensing (C. Zhu et al., 2022, p. 29), location-based recommendations (e.g., the next gas station (Constantinescu & Vladoiu, 2020, p. 4)), advertisement (Mekki et al., 2018, p. 3), or location-aware video analysis (X. Zhu et al., 2015)). Such services are “finally practical” (X. Zhu et al., 2015, p. 220) due to the usage of FSs, and are thus considered to be enabled by FC.

Location-aware services use the edge device's position to provide it with information relevant to edge devices and end users in that location. For example, FC may be used to provide fishing boats in a specific area with spatio-temporal data on fish schools in their vicinity (C. Zhu et al., 2022, p. 29) or in the case of VFC pothole and wild fire information may be distributed to vehicles in the relevant areas (Maheswaran et al., 2019, p. 2). On another note, a location-aware service may also gather data from a specific region and perform analysis on that data (location-aware media content mining (X. Zhu et al., 2015, p. 220)), which allows for “localized reflex decisions” (Hussain & Beg, 2019, p. 9) in a smart grid’s reaction to hazards. Location-aware services may also include services for other FNs or in combination with other FNs based on their location (e.g., traffic routing via smart traffic lights at intersections (Chun et al., 2016, p. 91)).

Closely related to location-aware services, context-aware services could be identified. Such services are characterized by taking into consideration the location and situation the service user is in, as well as information about the user or their end devices. For example, FSs can use end users’ preferences and advertisements to serve users with the best matching advertisements via Wi-Fi (Mekki et al., 2018, p. 3). Furthermore, information from other domains can be used by FNs for decision making, if contextually useful. Like this traffic may be rerouted in case of too much gas pressure in pipelines beneath certain roads by smart traffic lights using the context-relevant information provided by the FNs responsible for gas pipeline surveillance (Rampérez et al., 2018, p. 6).

Context-aware services and location-aware services are often presented alongside each other, as the location of end users may be useful context and vice versa.

In general, it can be observed, that applications provided in literature do not only rely on one service type but combine them. For example, in the case of disaster management and levee surveillance (Brzoza-Woch et al., 2016), FC may provide location-aware services in combination with context-aware services, being a local applications, whereas I can find latency-sensitive, real-time applications for data statistics and analysis in medical settings (e.g., Hassan et al. (2020)).

4.1.3. Fog Computing Business Values

Out of the 58 articles included in the review, 44 described what goals they want to achieve by using FC. During the TA, four themes were identified, “Internal Values”, “External Values”, “Border-Values”, and “MISC BV”. These themes include a total of 32 different business values.

Figure 8 shows the resulting thematic map of FC business values based on the reviewed literature.

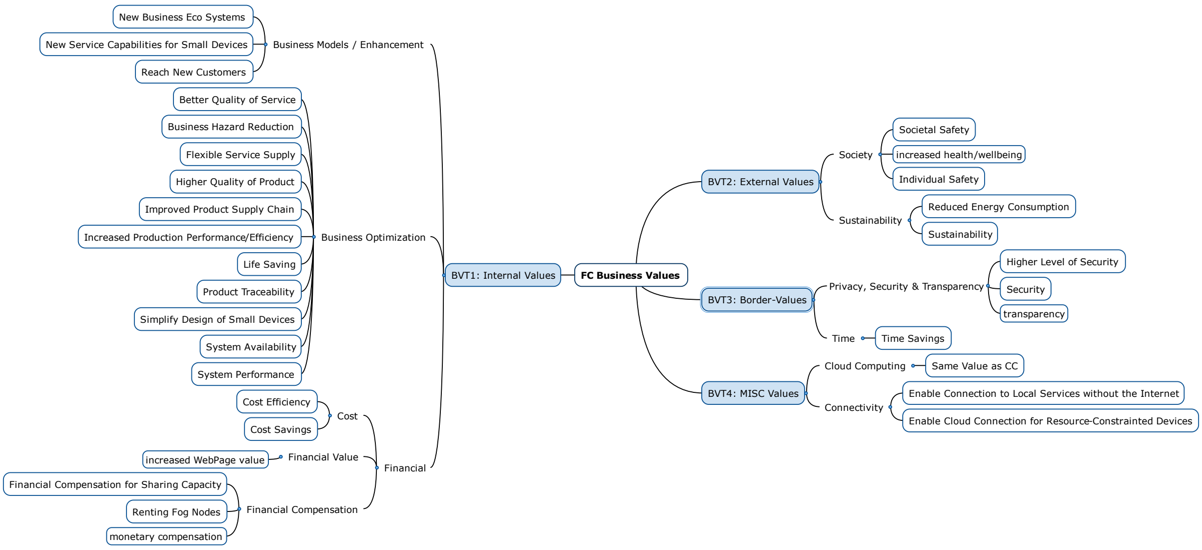


Figure 8: Thematic Map of FC business values

Theme BVT1: Internal Values

The first theme identified for FC business values is “Internal Values”. This theme comprises of business values that affect the organization putting the FS to use itself. The theme encompasses three sub-themes. An overview of these and the business values grouped therein, a short description, the number of publications, and the validation status in the text extracts used to derive the business values, can be obtained from Table 15.

The first level-one sub-theme for “Internal Values” is *business models / enhancement*. Organizations can use FSs to enhance their current business models or create entirely new ones. FC allows for the creation of entirely ‘new business eco systems’. This can be argued to be a business value in of its own, as it allows for novel value creation paths. For example, C. Zhu et al. (2022, p. 30) stated that smart ocean business eco systems have attracted the attention of different stakeholders (telecommunication, shipping, fisheries etc.). Like this novel businesses about providing accurate, prompt and real time information about fish schools could emerge from cooperations between fisheries and network operators. Also new ownership types of cars and commercial car-related services (Constantinescu & Vladoiu, 2020, p. 4) are opened up as new business opportunities, as well as mobile computing platforms (S. Singh et al., 2016), and distributed blockchain-based business markets (Nadeem et al., 2019).

Table 15: Overview of business values in the top-level theme „Internal Values“

Sub-Level 1 Theme	Sub-Level 2 Theme	Business Value	Description	Exemplary Papers
Business Models / Enhancement		New Business Ecosystem (4, o)	Entirely new business ecosystems based on FC services and FC affordances.	C. Zhu et al. (2022), Constantinescu and Vladoiu (2020), S. Singh et al. (2016), Nadeem et al. (2019)
		New Service Capabilities for Small Devices (1, o)	Enablement of new service capabilities provided by and for small and cheap devices.	Cao et al. (2019)
		Reach New Customers (1, o)	FC enables for reaching new customer (groups) with services.	Mekki et al. (2018)
Business Optimization		Better QoS (12, +)	Clients can be served with better quality services.	Cao et al. (2019), Santos et al. (2021), Pecori (2018), Hernández-Nieves et al. (2020)
		Higher Quality of Product (3, o)	Products can be produced with higher quality.	Tsipis et al. (2020), Hernández-Nieves et al. (2020), Hassan et al. (2020)
		Business Hazard Reduction (1, o)	Mitigation/Reduction of risks for mission critical elements of organizations value creation.	Tsipis et al. (2020)
		Flexible Service Supply (1, o)	Provision of different levels of service enabeling more flexible service supply.	Cao et al. (2019)
		Improved Product Supply Chain (1, o)	Improvements in product supply chain for information products provided via FSs.	Cao et al. (2019)
		Increased Production Performance /Efficiency (1, o)	Improvements in production performance and efficiency in, for example, industrial workshops.	Fraga-Lamas et al. (2020)
		Life Saving (11, o)	Human lifes can be saved by employing FSs and usage of services provided via these.	Mekki et al. (2018), Huang et al. (2017), Dar et al. (2018), Priyadarshini et al. (2018)
		Product Traceability (1, o)	Enhancements in product traceability within, for example, industrial workshops.	Fraga-Lamas et al. (2020)
		Simplify Design of Small Devices (1, o)	The desing of small or cheap devices gets more simple.	Cao et al. (2019)
		System Availability (6, +)	Increased and more reliable system availability of FSs.	Alam et al. (2021), Cao et al. (2019), Brzoza-Woch et al. (2016), Ilyas et al. (2022)
		System Performance (17, +)	System performance can be increased using a FS.	Khumalo et al. (2019), Silva et al. (2019), Chouikhi et al. (2019), Du et al. (2020)
Financial	Cost	Cost Efficiency (2, +)	FSs can provide services cost-efficiently.	Khumalo et al. (2019), Tahmasebi et al. (2020)
		Cost Savings (12, +)	Organizations can save costs for data transmission / communication and other organizational costs.	Constantinescu and Vladoiu (2020), X. Zhu et al. (2015), Hernández-Nieves et al. (2020), Beri et al. (2022)
	Financial Value	Increased WebPage Value (1, o)	Web page value can be increased using FSs to provide clients with web pages.	J. Zhu et al. (2013)
	Financial Compensation	Financial Compensation for Sharing Capacity (1, o)	Monetary compensation for organizations sharing capacity of their FS components.	Mekki et al. (2018)
		Monetary Compensation (1, o)	Monetary compensation for data stored or gathered within a FS, if provided to interested third-parties.	Vega et al. (2018)
		Renting Fog Nodes (1, o)	Organizations can rent complete FNs they own to third-parties.	Mai (2019)

Legend
Business Value: number = amount of publications the affordance was found in, o = argumentation only, + = empirical evidence

FC, further, allows for business model enhancement, as it may be used to provide services that formerly could not be provided by small/cheap devices. For example, in space technology FC can enhance the service capabilities provided by small satellites whilst simplifying the design of these satellites (Cao et al., 2019, p. 168), opening up novel business models.

Last but not least, FC has the business value to 'reach new customers'. FC allows for reaching new customers or for novel ways of reaching customers. For example, airports or shopping malls may use FC to store latest advertisements and promotions and provide them at low cost once an edge device is connected to the facilities Wi-Fi connection, bearing the users preferences in mind (Mekki et al., 2018, p. 3).

The second sub-theme for "Internal Values" is *business optimization.* This theme is comprised of business values that are concerned with optimizing an organizations current business performance, its products, or services.

The usage of FC services allows for a 'better QoS'. This may be in terms of less delay in service provision, for example, in Space Technology (Cao et al., 2019, p. 168) or in VR settings as human movement requires smooth service experience and rendering (Santos et al., 2021, p. 1039). But also, in terms of fine-tuned service experience, for example, having granular analysis of student performance and real-time feedback for fine-tuned educational services (Pecori, 2018, pp. 25–26) or better quality of customer support services (Hernández-Nieves et al., 2020, pp. 2, 10). Especially, real-time applications seem to benefit from lower latency (Alghamdi et al., 2019, pp. 8–11; Hassan et al., 2020, p. 17). If offering a service is the value creation for an organization better QoS may coincide with 'higher quality of product'. Higher quality of product describes that FC services allow for ensuring high product quality or even increase it by providing the information and services necessary for the businesses. For example, the continuous monitoring of olive groves helps to ensure a high crop quality and the quality of products made from these (Tsipis et al., 2020, p. 187). Furthermore, the quality of FinTech Products (Hernández-Nieves et al., 2020, p. 10) and healthcare may be increased (Hassan et al., 2020, p. 2).

FSs can be used to reduce business hazards. By relying on FC, for example, olive farmers can monitor their groves and take the necessary countermeasures and precautions as needed to reduce the risks of losing their groves to environmental conditions (e.g., wildfire, extensive rain, etc.) or pest infestation (Tsipis et al., 2020, pp. 187, 195-196).

FC services can be deployed to achieve 'increased production efficiency and performance'. For example, in Industry 4.0 settings the tracking of products and product elements (e.g., pipes in a shipyard) can improve the facilities performance (Fraga-Lamas et al., 2020, p. 45508). Such 'product traceability', however, may also be a business value on its own, as traceability is a challenge in these settings.

Sometimes, services and products based on FC are used in direct contact with humans and for their saving their lives. In these settings and organizations, FC can be deployed for a 'life saving' business value. For example, VFC systems can still take decisions and safety measures once the connection to the cloud is lost (e.g., because of natural disasters) (Mekki et al., 2018, p. 4), or by making sure that hazardous events are less likely (e.g., by reducing traffic congestion and car accidents (Huang et al., 2017, p. 107)). FSs can also be used to send help in case of accidents as soon as possible (Dar et al., 2018, p. 5) or provide information to rescue teams in case of the levee breaking and flooding (Brzoza-Woch et al., 2016, p. 2). This is especially a business value for organizations in medical settings where connectivity issues or latency may lead to false diagnosis resulting in a threat to the patient’s live (Silva et al., 2019, p. 1) and patients located remotely (e.g., elderly people living alone) need continuous monitoring (Priyadarshini et al., 2018, p. 3).

Several articles report ‘system availability’ and ‘system performance’ as their goal behind using a FC architecture. Using FC improves system availability with having up to 99% reliable service delivery, which is an improvement over cloud architectures, especially when the connection to the cloud is lost (Alam et al., 2021, p. 1392). But also in special settings, like space technology (Cao et al., 2019), disaster management (Brzoza-Woch et al., 2016), or healthcare (Ilyas et al., 2022; Mayer et al., 2021; Silva et al., 2019) system availability is considered important. As three out of the six articles concerned with system availability originate in the medical sector, and three of the seven articles that are coded for the medical sector report system availability as a goal, it seems to be highly important for medical applications. Similarly, system performance (four out of the seven medical articles report this), is an important FC business value. The usage of FSs improves system performance over the cloud setting. Khumalo et al. (2019) empirically validate this in a general setting, Silva et al. (2019) for medical applications, and Chouikhi et al. (2019) for their smart grids FC architecture. All of them find evidence for performance increases or delay reductions by relying on FC. Moreover, accuracy improvements for FC architectures is reported (Du et al., 2020, pp. 11004–11005).

FC services, furthermore, can be provided at different levels of service (‘flexible service support’) and information products, improving the commercial aerospace product supply chain (‘improved product supply chain’) (Cao et al., 2019, p. 169). Also reported for the space setting, FC can be used to achieve a ‘simplified design of small devices’ (Cao et al., 2019, p. 168). In this case satellites can be produced more cheaply and do not need extensive computing capabilities, as they can offload tasks to FNs.

As the third and last level-one sub-theme, *financial aspects*, covers all business values directly related to an organization’s finances in three level-two sub-themes.

Cost is concerned with increasing an organization’s ‘cost efficiency’ or reduce existing costs.

From a cost efficiency point of view, FC can be seen as a cost-efficient way to provide services (Khumalo et al., 2019, pp. 1–2; Tahmasebi et al., 2020, p. 9). This may help in providing underserved areas with necessary services (Khumalo et al., 2019, pp. 1–2). Thus, this might be one of the most important aspects of the novel technology, as it may increase the quality of life for underserved areas and people, for example by enabling a smart agriculture use case as described by (Khumalo et al., 2019, p. 3).

The usage of FC can lead to ‘cost savings’. This can be achieved in two ways. First, FC services can help to reduce organizations’ costs. This can be done, for example, by better fuel management for organizations own vehicles or alerts for upcoming payments (Constantinescu & Vladoiu, 2020, p. 4), lower cost high security services, such as biometrical badge security for facility management (X. Zhu et al., 2015, p. 219), energy consumption scheduling for buildings (Chouikhi et al., 2019, pp. 1820–1821), reduced entity management cost for FinTech (Hernández-Nieves et al., 2020, p. 2), or by providing healthcare at the patients doorstep (Beri et al., 2022, p. 7610). This business value is also a benefit for other entities using the organizations services, such as other companies or private individuals and could thus also be placed within the "Border-Values" theme. However, as the rest of the theme is related to the organization providing FC services, it was decided to still be placed here. A more thorough discussion with other researchers may lead to changes in that decision, but was not performed (see the limitations described in section 5.3).

The second way leading to cost savings is by reducing the cost of the provided services. This can be achieved via lower transmission/communication cost (Constantinescu & Vladoiu, 2020, p. 5; Khumalo et al., 2019, p. 5; Mirzaie et al., 2021, pp. 591, 593-594), especially by not accessing the cloud (Soua & Tohme, 2018, p. 7), energy-efficiency (Luo et al., 2021, p. 248), low-cost or already existing devices (Dar et al., 2018, pp. 2, 5; Tsipis et al., 2020, p. 175), and local access-cost efficient management (Mekki et al., 2018, p. 4).

Besides *cost* related business values, FC can have *financial compensation* for providing services or resources. Organizations may receive 'monetary compensation' for data gathered by FS or sensors they possess. These data are valuable and may be provided to other entities via data marketplaces in return for monetary compensation (Vega et al., 2018, p. 11).

Furthermore, organizations may rent entire FNs ('renting fog nodes') (Mai, 2019, p. 5) or share capacity they have left on their infrastructure ('financial compensation for sharing capacity'), such as smart vehicles (Mekki et al., 2018, p. 3). However, no business model for renting fog nodes has emerged yet (Mai, 2019, p. 5).

Finally, FC can increase *financial values* already existing within an organization's assets. Like this 'increased web page value' can be achieved by relying on a FC architecture to provide the end users with that website (J. Zhu et al., 2013). However, this sub-theme is not well supported by the literature reviewed.

Theme BVT2: External Values

Other than "Internal Values", the theme "External Values" captures business values that have effects outside of the organization relying on the FS. The theme encompasses two sub-themes, *society*, and *sustainability*. These business values are, although not affecting the organizations themselves, of value to them and to their social, and ecological environments. An overview of the business values captured by "External Values", a short description for each, the number of publications they were found in, and their validation status (o/+), can be obtained from Table 16.

Table 16: Overview of business values in the top-level theme „External Values"

Sub-Level 1 Theme	Business Value	Description	Exemplary References
Society	Increased Health / Wellbeing (1, +)	Personal health and well being can be increased by relying on FSs.	Cerina et al. (2017)
	Individual Safety (2, o)	Individual safety people affected by FSs can be increased.	Huang et al. (2017), Du et al. (2020)
	Societal Safety (4, +)	FSs enhance safety of modern societies critical supplies (e.g., electricity, water,…)	Mirzaie et al. (2021), Jaiswal et al. (2020), Chouikhi et al. (2019), Fan et al. (2018)
Sustainability	Reduced Energy Consumption (2, o)	FSs reduce the energy necessary to provide cloud-like services.	Khumalo et al. (2019), Cha et al. (2018)
	Sustainability (4, o)	FS usage leads to more sustainability in every day life and when providing services.	Constantinescu and Vladoiu (2020), Luo et al. (2021), Maheswaran et al. (2019), Huang et al. (2017)
Legend Business Value: number = amount of publications the affordance was found in, o = argumentation only, + = empirical evidence			

The sub-theme *society* captures business values that are related to the people using the services provided via FC and to the general society, which can benefit from organizations providing FC services.

The usage of FC services may lead to 'increased health/wellbeing' for individuals. For example, Cerina et al. (2017) describe a smart ambient application measuring the air quality to improve personal health and productivity.

'Individual safety' of vehicle passengers and other traffic participants may be achieved by relying on VFC, due to traffic safety enhancement and traffic control applications (Huang et al., 2017, p. 106) or platoon sensing (Du et al., 2020, pp. 10998–10999).

Besides individual safety also society can benefit from FSs by achieving 'societal safety'. This goal can be observed in smart grid and smart city (water distribution) settings. Both are fundamental for modern society and ensuring their functionality and safety is essential for social peace and safety of population. This may be done by providing services for urban water distribution anomaly detection (Mirzaie et al., 2021) or by scheduling energy consumption in a way that reduces power outages and demand peaks via smart grid services (Chouikhi et al., 2019, pp. 1817, 1820; Jaiswal et al., 2020, pp. 1, 3). Also, surveillance of smart infrastructures that are critical for society (e.g., water transfer projects (Fan et al., 2018)).

The second "External Values" sub-theme is *sustainability*. *Sustainability* is concerned with business values that have an impact on organizations environmental surroundings and thus benefit not necessarily the organizations themselves but serve a general purpose.

FC can aid in reducing the amount of energy necessary to provide cloud-like services (Khumalo et al., 2019, p. 5). Cloud data centers provide intensive computing capabilities, but therefore, a large amount of energy is necessary (Brdar, 2022). The energy consumption of cloud services is a major pain point of CC. 'Reduced energy consumption' is especially valuable in times of climate change, fossil energy and energy shortages.

But not only reduced energy consumption is of interest for *sustainability*. The reviewed literature also reveals 'sustainable practices' that may be a goal of FSs. FC in connection with interconnected environments allow for a more sustainable way of life (Constantinescu & Vladoiu, 2020, p. 2). Furthermore, fuel management activities for vehicles and reducing pollution (Constantinescu & Vladoiu, 2020, p. 4), and energy-efficiency (Luo et al., 2021, p. 248) may lead to more sustainability, as well as incorporating eco-friendly mobility (e.g., bikes, e-bike) into city traffic by FC-based road observers in a safe way (Maheswaran et al., 2019, p. 3), or reducing road traffic congestion (Huang et al., 2017, p. 107).

Theme BVT3: Border-Values

As a third top-level theme, "Border-Values" was identified. "Border-Values" consists of business values that can be a goal of both organizational actors and non-organizational actors. The theme is split into two level-one sub-themes. An overview of the business values captured by "Border-Values" and the sub-themes they form can be obtained from Table 17.

Table 17: Overview of business values in the top-level theme „Border-Values"

Sub-Level 1 Theme	Business Values	Description	Exemplary Publications
Security & Transparency	Higher Level of Security (4, +)	FSs achieve higher security levels as previously employed systems.	H. Zhang et al. (2020), C. Zhu et al. (2022), S. Chang et al. (2020), X. Zhu et al. (2015)
	Security (General) (3, +)	FSs achieve general security for organizations.	X. Zhu et al. (2015), H. Zhang et al. (2020), Vega et al. (2018)
	Transparency (1, o)	FSs achieve transparency.	Hernández-Nieves et al. (2020)
Time	Time Savings (6, o)	FSs can reduce the time necessary to perfom certain services or actions.	Constantinescu and Vladoiu (2020), Ilyas et al. (2022), Du et al. (2020), Beri et al. (2022)
Legend Business Value: number = amount of publications the affordance was found in, o = argumentation only, + = empirical evidence			

Security and transparency is concerned with business values related to privacy and 'security' goals actors may have. The usage of FC can have the goal security for an organization. For example, FC may secure bring-your-own-device strategies by having virtual desktop infrastructures that can be provided efficiently and with additional security plugins by using FC (X. Zhu et al., 2015, p. 216). Also, security services for facility management are possible via FC that are not possible without (X. Zhu et al., 2015, p. 219). In general, security operations provided by FS are proven to perform at least as good as those provided by cloud-only architectures for several attack types (data injection attacks and replay attacks), while simultaneously being more suitable for industrial data bursts (H. Zhang et al., 2020, pp. 664–665). FC may further be used bearing a 'higher level of security' for the entities in the system in mind. Adding to the attack types mentioned under security, FSs are reported to better mitigate reset attacks and denial of service attacks (H. Zhang et al., 2020, p. 665). Moreover, security patches can be uploaded from FNs to vessels in their vicinity or malware detection can be provided to them as a service (C. Zhu et al., 2022, p. 29). Also, data encryption can take place at the FNs to achieve "a first layer of privacy protection" (S.

Chang et al., 2020, p. 5) and security. Security can be a business value, to organizations (e.g., security services for facility management (X. Zhu et al., 2015, p. 219)) and to non-organizational actors (e.g., security patches and malware protection for vessels (C. Zhu et al., 2022, p. 29) individuals are currently using and is, thus, considered a “Border-Value”. ‘Transparency’ is reported as an important goal for the FinTech domain (Hernández-Nieves et al., 2020, p. 2), but not further investigated or supported by other of the reviewed articles. This business value seems to serve non-organizational purposes and organizations simultaneously.

The second level-one sub-theme for “Border-Values” is *time*. *Time* captures the ‘time savings’ business value FC achieves. This may be achieved during up- and downloading of data (Constantinescu & Vladoiu, 2020, p. 3) or during calculation, storage and processing (Ilyas et al., 2022, p. 6). Furthermore, the training time of ML models can be significantly reduced by usage of FC and distributed learning (Du et al., 2020, pp. 11004–11005). FSs in medical settings achieve time savings for both doctors and patients, as doctors can remotely assess patients and provide suggestions and patients do only need to go see a doctor if necessary (Beri et al., 2022, p. 7610) or may be deployed to save rescue time in case of accidents (Dar et al., 2018, p. 5). Especially, in the medical setting, the organizational (doctors, rescue teams) and non-organizational (patients, victims of accident) side of this business value can be clearly observed.

Theme BVT4: MISC Values

The last top-level business value theme is “MISC Values”. This theme comprises of business values that could not be fit into any other theme and are thus considered miscellaneous. The theme encompasses three business values in two sub-themes. An overview of the theme “MISC Values” and the business values grouped therein, as well as a short description, the number of publications they were found in, and their validation status (o/+), can be obtained from Table 18.

Table 18. Overview of business values in the top-level theme „MISC Values“

Sub-Level 1 Theme	Affordance	Description	Exemplary Publications
Cloud Computing	Same Value as CC (1, o)	FC achieves the same commercial value as CC.	Mai (2019)
Connectivity	Enable Connection to Local Services Without Internet Connection (1, o)	FC achieves connection to local services for resource-constrainted edge devices.	Constantinescu and Vladoiu (2020)
	Enable Cloud Connection for Resource-constrainted Devices (3, o)	FC achieves cloud connection for resource-constrainted edge devices.	C. Zhu et al. (2022), Cha et al. (2018), Cao et al. (2019)

Legend
Business Value: number = amount of publications the affordance was found in, o = argumentation only, + = empirical evidence

For the miscellaneous sub-theme *cloud computing*, FC is reported to commercially be of ‘same value as CC’ (Mai, 2019, p. 5). This is the only instance such a statement could be found.

The sub-theme “connectivity” is concerned with business values focused on the enablement of special types of connections for end users’ devices. FC can be used to connect end users to local services even without internet connection, directly benefiting the users (Constantinescu & Vladoiu, 2020, p. 2).

FC can further be used to connect resource constrainted devices to the cloud or other computing nodes, improving several aspects like energy consumption and life cycle cost (C. Zhu et al., 2022, p. 28), as it "makes cloud services available near IoT devices and mobile users" (Cha et al., 2018, pp. 8–9).

Both sub-themes are only weakly supported and cannot be clearly placed into any other top-level theme. Arguably the best suitable other theme would be “Border-Values”, as all business values reported for “MISC Values” may be goals of either of organizational actors or non-organizational ones. However, it can be argued that same value as CC may not even be a goal for any actor and, thus, needed be deleted. For comprehensive reporting of all potential business value instances and since the term “commercial value” (Mai, 2019, p. 5) has been chosen by the authors, it was decided to keep same value as CC and report it as a miscellaneous business value.

4.2. Business Value Creation Sets

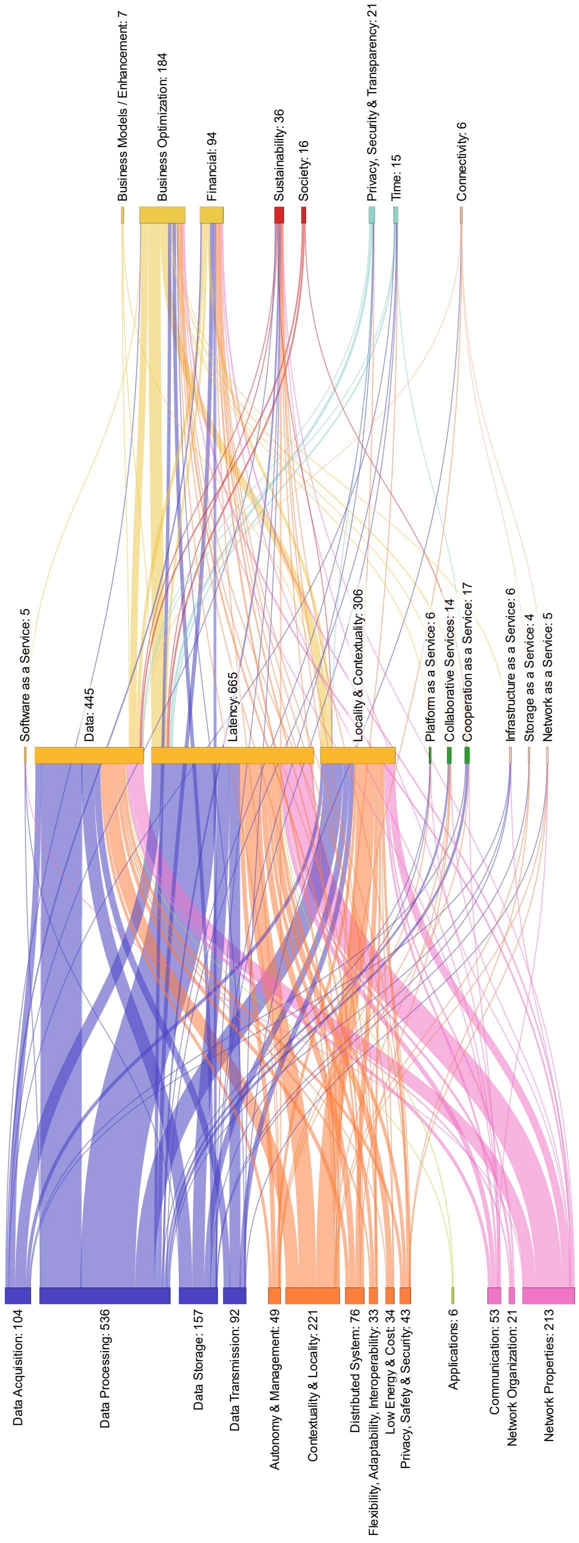
As the TA revealed themes for affordances, services and business values, these themes were used to create a Sankey diagram of connections between the themes for affordances, the service themes and the business value themes. The created Sankey diagram is shown in Figure 9. It provides a color-coded and thematically ordered overview of connection flows from affordance themes over service themes to the business value themes.

Looking at Figure 9 several general observations can be made.

First, not all themes reported in section 4.1.3 for the business values can be found in the figure. While for the affordance and service top-level themes all sub-themes are covered through connections with either service themes or business value themes, not all business value themes were recovered, as the subtheme *cloud computing* is missing for “MISC Business Values”. As this theme, however, was only reported in one text extract, this is not surprising.

Second, the service theme “Software as a Service” is dominantly interconnected with affordances and business values in the reviewed literature supporting the already made observation, that FC services mostly focus SaaS rather than PaaS or IaaS. However, it must be acknowledged that the other two service top-level themes are still covered by connection flows and thus could be used by organizations to generate business value.

Third, it becomes apparent, that the reviewed literature primarily discusses connections between the affordance level and the service level, and connections between service level and business value level are drawn less frequently. This can be identified in Figure 9 by considering the incoming and outgoing flows at the service level. For every node at the service level the number of incoming flows is (substantially) higher than the number of outgoing flows. The node height is proportional to the number of incoming flows and for every service node there is a discrepancy between node height and outgoing flows leaving some part of the node displayed without outgoing flows.



Legend

Affordance top-level themes:
🟦 Data
🟧 Fog System Properties
🟪 Network
🟩 MISC Affordances

Service top-level themes:
🟨 Software as a Service
🟩 Platform as a Service
🟧 Infrastructure as a Service

Service top-level themes:
🟨 Internal Values
🟥 External Values
🟦 Border-Values
🟧 MISC Business Values

Figure 9: Sankey diagram of connections ordered by theme and color-coded

This may partially be due to there, fourth, being connections directly form the affordance level to the business value level. For example, the affordance level-one sub-theme *data processing* is directly connected to the business value level-one sub-themes *business optimization* and *financial*. Such connections were not involved in the following descriptions and images of the BVCS for better visibility of the flows and clearer descriptions.

In general, it can be observed, that for most services, level-one sub-themes of “data”, “fog system properties”, and “network” are used. Most prominently for “data”, *data processing* and *data storage* can be observed for almost every service. *Contextuality & locality* and *distributed system* stick out for “fog system properties”, however, being mostly tied to SaaS level-one sub-themes. For “network” *network properties* is the dominant affordance level-one sub-theme, being strongly connected to the SaaS sub-themes *data*, *latency*, and *locality & contextuality*. For the business value side, *business optimization* and *financial* are most commonly connected. Less connected, but still clearly visible, connections for *sustainability*, *society*, and *privacy*, *security & transparency* can be observed. Most connections flow from the SaaS themes *data*, *latency*, *locality & contextuality* and only few connections can be seen for PaaS or IaaS themes.

The most prominent general BVCS are described subsequently. For the sake of better understanding and visibility, an abbreviation of the theme name is displayed in brackets before each code name for the affordance and business value level. For the service level this is not done as service themes are always discussed as a package. The correct mapping of abbreviations and theme names can be seen in Table 19. However, not all these abbreviations are necessarily used in the following visualizations.

Table 19: Mapping of theme name abbreviations to theme names for affordances (left) and business values (right)

Abbrev. of Affordance Theme	**Name of Affordance Theme**
[DA]	Data Acquisition
[DP]	Data Processing
[DSt]	Data Storage
[DT]	Data Transmission
[AM]	Autonomy & Management
[CL]	Contextuality & Locality
[DSy]	Distributed System
[FAI]	Flexibility, Adaptability, Interoperability
[EC]	Low Energy & Cost
[PSS]	Privacy, Safety & Security
[Ap]	Applications

Abbrev. of Business Value Theme	**Name of Business Value Theme**
[BME]	Business Models / Enhancement
[BO]	Business Optimization
[CC]	Cloud Computing
[Con]	Connectivity
[Fi]	Financial
[PST]	Privacy, Security & Transparency
[So]	Society
[Su]	Sustainability
[Ti]	Time
[Com]	Communication
[NO]	Network Organization
[NP]	Network Properties

BVCS01: Relying on FCs' "data", *contextuality & locality*, and *network properties* affordances to provide *data-related services* for *business optimization* and *financial* business values.

The first BVCS is concerned with data-related services. Figure 10 provides an overview of the flow connections within BVCS01.

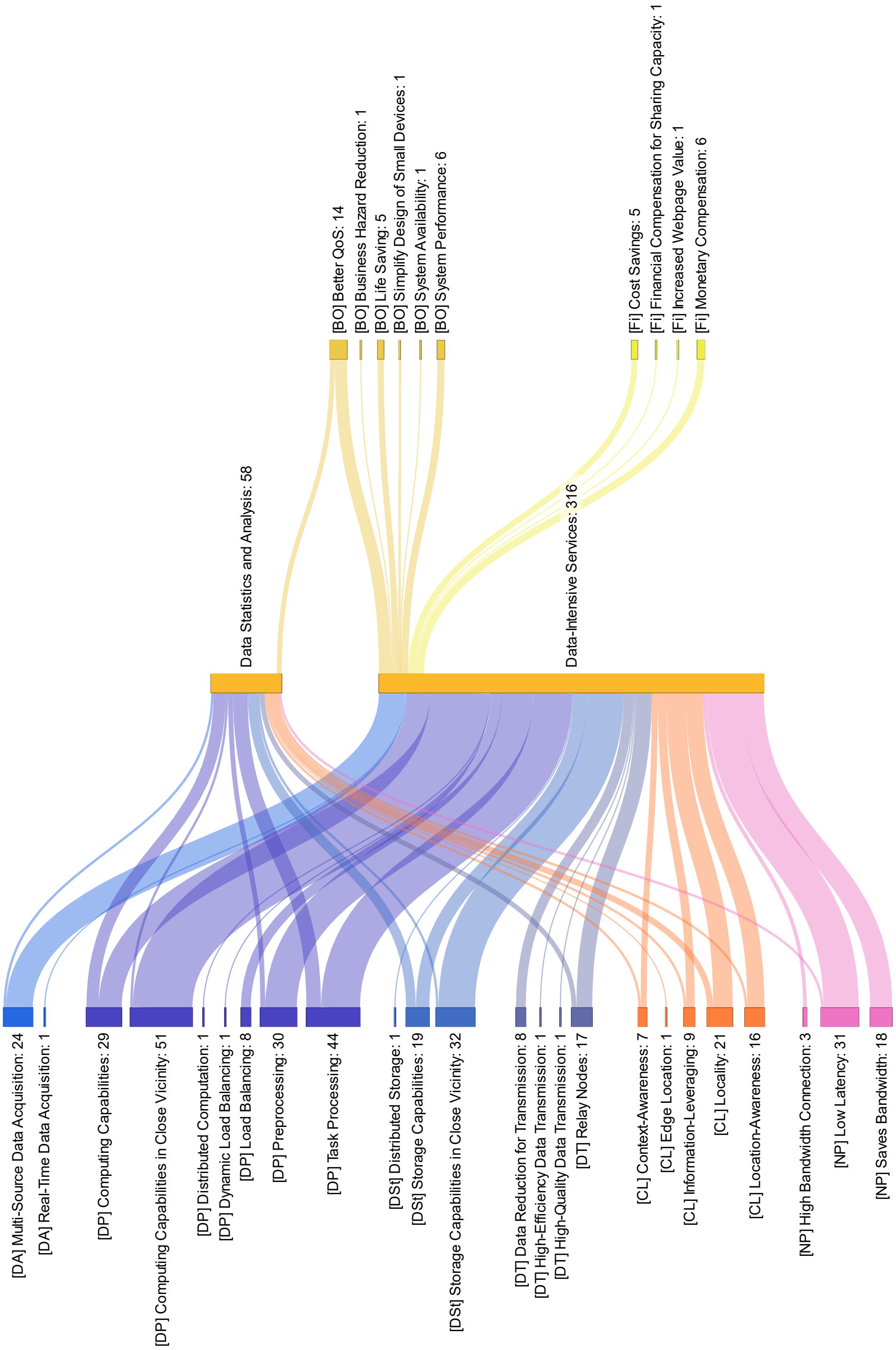


Figure 10: Color-coded and thematically grouped connection flows for the BVCS01

As can be observed in Figure 10, all four "data" affordances are used to create *data-related services*, with *data processing* having the overall largest incoming flow. Furthermore, these services strongly rely on the "fog system properties" sub-theme *contextuality & locality* as well as the "network" sub-theme *network properties*. Most of the connections (316 out of 374) relate to data-intensive services. While the relative strength of flows, and, thus, the connection strength, for *data processing* (e.g., task processing, computing capabilities) remains roughly the same for both *data-related services*, the strength of *data storage*, *contextuality & locality*, and *network properties* varies substantially. This indicates, that while *data processing* seems to be equally important to both services, *data storage* affordances (e.g., storage capabilities, storage capabilities in close vicinity) and *contextuality & locality* affordances (e.g., location-awareness, context-awareness, locality) may be more important for data statistics and analysis services, whereas *network properties* affordances (e.g., low latency, saves bandwidth) play a bigger role for data-intensive services.

Paying a closer look to *data storage*, it becomes apparent, that data statistics and analysis services heavily rely on the storage capabilities (80,00% of *data storage* connections for this service) of FSs, while for data-intensive services, the affordance of having storage capabilities in close vicinity is valuable (71,43% of *data storage* connections). A similar pattern can be seen for *data processing*, where computing capabilities is prominently discussed for data statistics and analysis and computing capabilities in close vicinity is considered important for data-intensive services.

The *network properties* affordances are almost only discussed for data-intensive services, indicating, that while data storage and analysis makes use of *data processing*, *data storage*, and *contextuality & locality* affordances, low latency and saves bandwidth is almost entirely a concern of data-intensive services. Similarly, the *data transmission* affordances are mainly connected to data-intensive services, with relay nodes and data reduction for transmission being the most important. Relay nodes can also be observed for data statistics and analysis. The same holds true for the *data acquisition* affordances. Here, multi-source data acquisition is found an affordance to rely on for data-intensive services.

In total, computing capabilities in close vicinity (51 connections), task processing (44 connections), storage capabilities in close vicinity (32 connections), and low latency (31 connections) are the most occurring for this BVCS.

Looking at the other end of the connection flows, to see which business values can be achieved by *data-related services*, I find *business optimization* and *financial* business values being discussed in the literature. Data analysis and statistics is thereby only connected to better QoS. Having, for example, statistical analysis of students' educational progress can increase the quality of teaching services and learning platforms (Pecori, 2018, pp. 25–26) and statistical knowledge on devices webpage rendering speeds can increase the quality of browser services and webpage display by adapting, for example, the image quality depending on a user's device and connection (J. Zhu et al., 2013, p. 323). For data-intensive services one can observe that the business values better QoS, life saving, system performance and monetary compensation are achieved by FSs. Monetary compensation, for example, is discussed for a FC-based data marketplace described by Vega et al. (2018), where sellers can sell the data gathered by their sensors and stored and processed locally at FNs to interested buyers utilizing blockchain technology and smart contracts.

BVCS02: Relying on FCs' *data acquisition, data processing, contextuality & locality*, and *network properties* to provide *latency-related services* for *business optimization* business values.

The second BVCS encompasses *latency-related services* that can be employed for reaching *business optimization* business values. Figure 11 provides an overview of BVCS02.

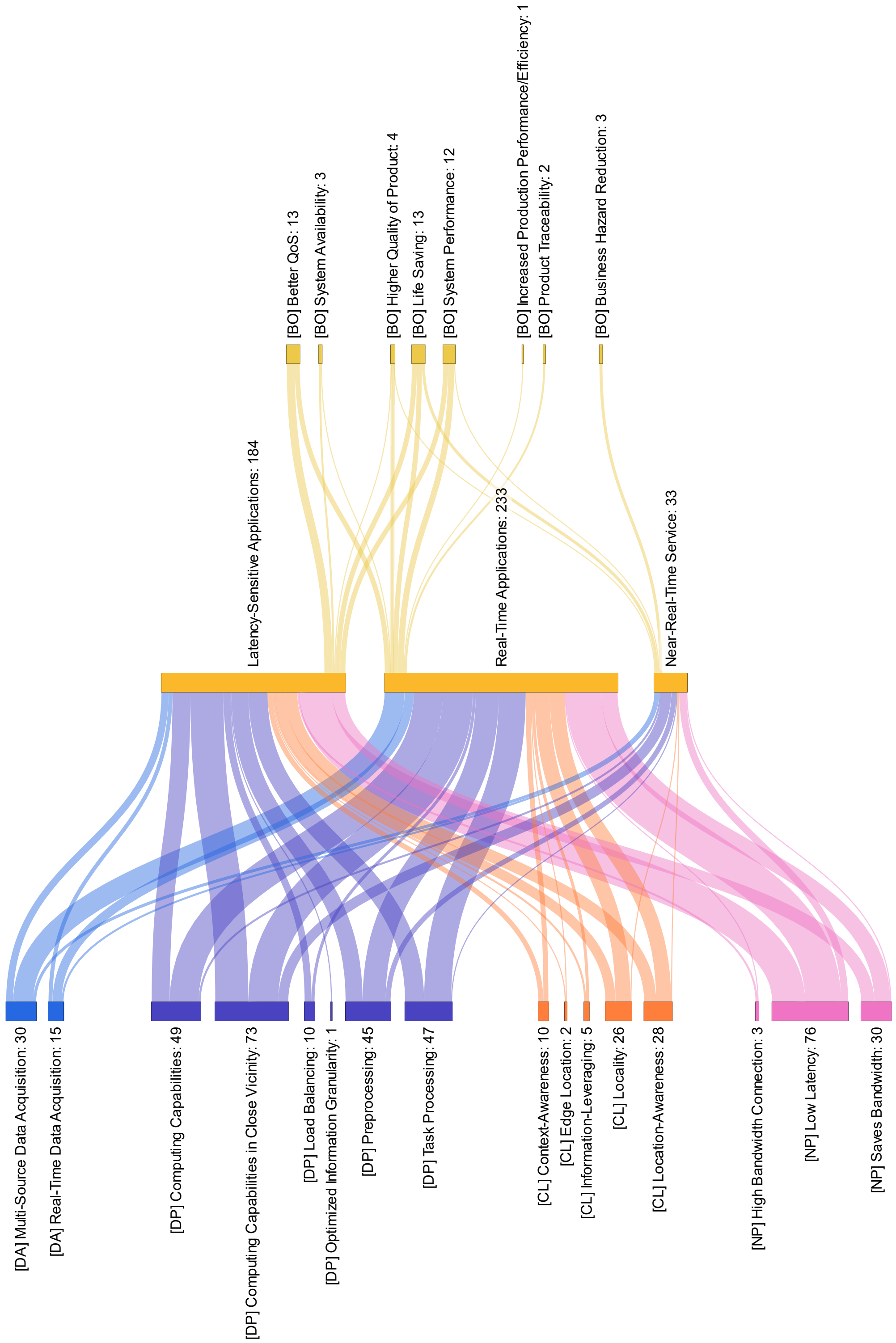


Figure 11: Color-coded and thematically grouped connection flows for the BVCS02

In contrast to BVCS01 not all "data" affordance themes are present for *latency-related services*. Only *data acquisition* and *data processing* play a greater role for *latency-related services*. While *data* *processing* is similar important for all three services considered latency-related, *data acquisition* is found not as relevant for latency-sensitive applications as for the other two services. *Contextuality & Locality* on the other hand are reported less frequently for a near-real-time service.

Analyzing the affordance themes more closely, it is revealed that while all three services rely on the *contextuality & locality* affordances locality and location-awareness, the other affordances for this theme are not considered relevant for a near-real-time service. It can be further observed that *data acquisition*, *data processing,* and *network properties* affordances are considered in similar frequencies by the reviewed literature for all three services, with only minor nuances in importance.

Overall, it can be observed that the affordances computing capabilities in close vicinity (73 connections), low latency (76 connections), and computing capabilities (49 connections), are contributing the most to *latency-related services*, followed by task processing (47 connections) and task processing (45 connections).

Organizations may achieve *business optimization* goals by relying on *latency-related services*. Both latency-sensitive applications and real-time applications can contribute to better QoS, by, for example, reducing response time (Hussain & Beg, 2019, p. 24), which is especially important to VR applications that require imperceptible latency for accurate and smooth movement within the application (Santos et al., 2021, p. 1039), or by meeting QoS requirements in electronical medical applications (Hassan et al., 2020, p. 17).

All three *latency-related services* can be used to achieve the business value life saving, which is, again, a value mostly for the medical sector, but also for personal transportation settings in smart cities and VFC. By relying on a near-real-time-service, Beri et al. (2022), continuously monitor pregnant women’s health parameters to offer immediate help if necessary due to dire health conditions.

Furthermore, system performance can be increased by *latency-related services*, exemplarily in space technology, where space-based FC is considered to improve the real-time performance for space information networks (Cao et al., 2019, p. 167) or for digital twins (Knebel et al., 2021, p. 2).

Increased production performance/efficiency and product traceability are reported business values for real-time applications deployed for pipe traceability in an industrial shipyard (Fraga-Lamas et al., 2020, p. 45508).

Special to near-real-time service is the business value of business hazard reduction. This is used in a smart agriculture setting, where olive growers can monitor their crops in near-real-time to detect pests and diseases within their olive groves and critical environmental circumstances (e.g., summer fires, extensive rain, etc.) (Tsipis et al., 2020, pp. 187, 195-196) that can threaten the foundation of their businesses. Such services seem especially important considering the current climate developments and extensive wildfires in these regions during summer season (Pompl, 2023; Schmitz, 2022).

BVCS03: Relying on FCs' *data processing, data storage, contextuality & locality, distributed system,* and *network properties* affordances to provide *locality & contextuality-related services* for *business optimization* and *financial* business values.

BVCS03 covers *locality & contextuality-related services* that are reported to be useful for *business optimization* and *financial* business values. Figure 12 provides an overview of BVCS03.

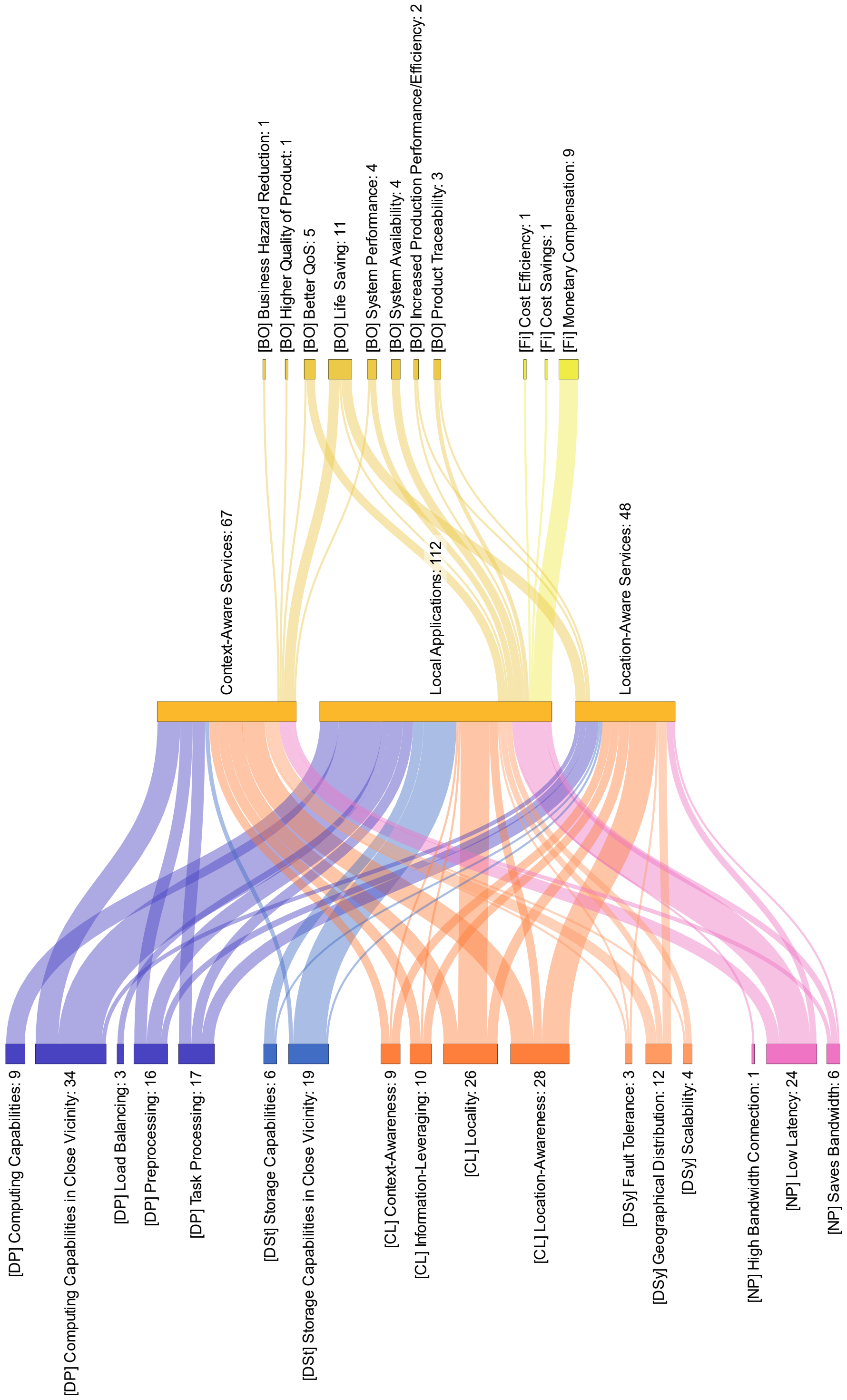


Figure 12: Color-coded and thematically grouped connection flows for the BVCS03

Like for BVCS02 it can be observed that not only two of the four “data” affordance themes are discussed frequently for *locality & contextuality-related services*. However, *data acquisition* is switched out for *data storage*, mainly due to local applications heavily relying on the two reported *data storage* affordances. Context-aware services and location-aware services are strongly connected to *contextuality & locality* affordances, mainly location-awareness, whereas local applications makes use of FC’s locality affordance and almost ignores context-awareness and information-leveraging. *Data processing* affordances are similarly important for all three services, with local applications relying the most on them, by using the computing capabilities and computing capabilities in close vicinity afforded by FC. Context-aware services and location-aware services employ computing capabilities in close vicinity, but also preprocessing and task processing, not as frequently reported for local applications. Out of the *network properties* theme low latency is the most prominent and equally important to all three services. Newly introduced by BVCS03, I find *distributed system* affordances in use. All three services make use of geographic distribution. For local services, furthermore, scalability is an affordance reported relatively frequently and location-aware services also are reported to make use of FC’s fault tolerance affordance.The most common affordances are computing capabilities in close vicinity (34 connections), location-awareness (28 connections), locality (26 connections), and low latency (24 connections).

From a business value perspective, two themes are identified holding goals for *locality & contextuality-related services*, *business optimization* and *financial*.

Financial business values are only reported for local applications, with monetary compensation making up the biggest portion of connections for this theme. This is due to the already briefly described FC- and blockchain-based peer-to-peer data marketplace, where sellers can offer locally stored and processed data to interested buyers, making use of locally placed blockchain peers (Vega et al., 2018).

For *business optimization*, again, better QoS, life saving, and system performance are reported business values. Better QoS by relying on local applications is, for example, possible in content delivery networks, where clients can now be served from local FNs rather than the more distant cloud data centers (Alghamdi et al., 2019, p. 8).

Life saving through *locality & contextuality-related services* is reported for smart city environments (see Rampérez et al. (2018)), disaster management (see Brzoza-Woch et al. (2016)), and VFC settings (see Maheswaran et al. (2019)). For example, all three service-types can be used in a combined fashion in disaster management for flood-risk assessment and early warning (Brzoza-Woch et al., 2016, p. 2) or for acting across domains in case of locally detected gas pressure anomalies in smart cities (Rampérez et al., 2018, p. 6) to save people in the area of incident from potential (deathly) consequences.

In similar disaster situations, system performance and system availability can be enhanced by local applications, as cloud information may not be accessible reliably and performant due to cut or bad internet connection in the affected areas. Information provided to rescue teams by local FNs can increase both performance and availability of rescue services (Brzoza-Woch et al., 2016, p. 4). Both business values are also reported for medical settings (see Mayer et al. (2021)).

BVCS04: Relying on FCs' *data acquisition, data processing, data storage, autonomy & management, communication, contextuality & locality*, and *network properties* affordances to provide "*Platform as a Service"* for *business optimization* and *society* business values.

The fourth BVCS leverages FC affordances to provide *PaaS*. In contrast to the BVCS related to *SaaS* themes, the top-level theme and code PaaS is considered in the overview graphic (Figure 13) below. This is possible, as there are only two services mapped to "PaaS" and no sub-themes emerged during the TA, like for *SaaS*, where the sub-themes enable a more fine-grained discussion.

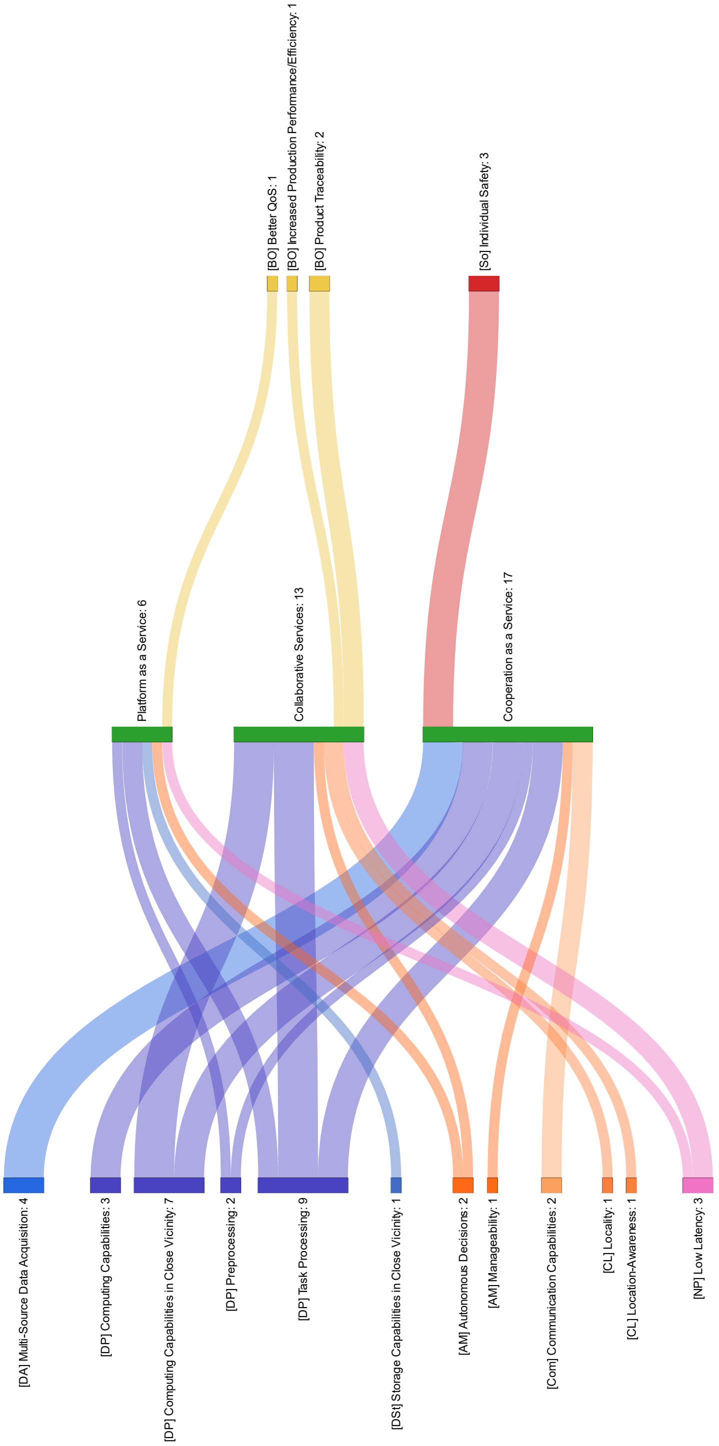


Figure 13: Color-coded and thematically grouped connection flows for the BVCS04

Figure 13 reveals that many affordance themes, the most up to now, are involved in the provision of “PaaS” services. This is because, the separate services rely on different affordances and affordance themes for the most part. All three services have in common, that they employ *data processing* affordances. However, they do so on different levels. All rely on task processing, while general PaaS does also use preprocessing. For collaborative services and cooperation as a service, furthermore, computing capabilities in close vicinity are reported and computing capabilities in general for Cooperation as a Service.

Collaborative services, furthermore, rely on *contextuality & locality* affordances, which are not used by the other services in this theme. Cooperation as a Service on the other hand employs the *communication* affordance communication capabilities and the *data acquisition* affordance multi-source data acquisition. Platform as a Service, moreover, makes use of *autonomy & management* for a large part of used affordances.

The most reported affordances for this BVCS are task processing (9 connections) and computing capabilities in close vicinity (7 connections). Both are from the *data processing* theme, indicating this themes major relevance for BVCS04.

Considering the business values in this BVCS, individual safety can be achieved as a *society* business goal by relying on cooperation as a service. This is discussed by Du et al. (2020), who propose the usage of VFC to form a cooperative-sensing-platoon to ensure extensive coverage of a vehicle platoon’s surroundings. This leads to more individual safety for all traffic participants.

Collaborative services can be used for product traceability and increased production performance/efficiency, as proposed in an industry 4.0 setting (Fraga-Lamas et al., 2020, p. 45508).

PaaS in general is reported to be useful for achieving the business value of better QoS, for example, in educational applications (Pecori, 2018, pp. 25–26).

BVCS05: Relying on FCs’ *data acquisition, data processing, data storage, data transmission, contextuality & locality, communication, privacy, security & safety,* and *network properties* affordances to provide *IaaS services* for *connectivity* business values.

BVCS05 extends the coverage of the BVCS to the service level of “IaaS”. Figure 14 provides an overview of this BVCS.

First, the following observations need to be made. This BVCS encompasses the most affordance themes, eight in total. However, as already observed for BVCS04, which considered “PaaS”, the different services within the BVCS rely on mostly separate affordance themes.

The only affordance themes considered for more than one of the services in this BVCS are *privacy, security & safety* and *contextuality & locality*, relevant for network as a service and storage as a service, and *data storage* relevant for infrastructure as a service and storage as a service.

The *communication* affordance network connection is only considered by network as a service. The same holds true for relay nodes from *data transmission*.

Storage as a service is the service that has the most affordances in common with the other two services. Such services rely on *data storage*, *contextuality & locality*, and *privacy, security & safety*.

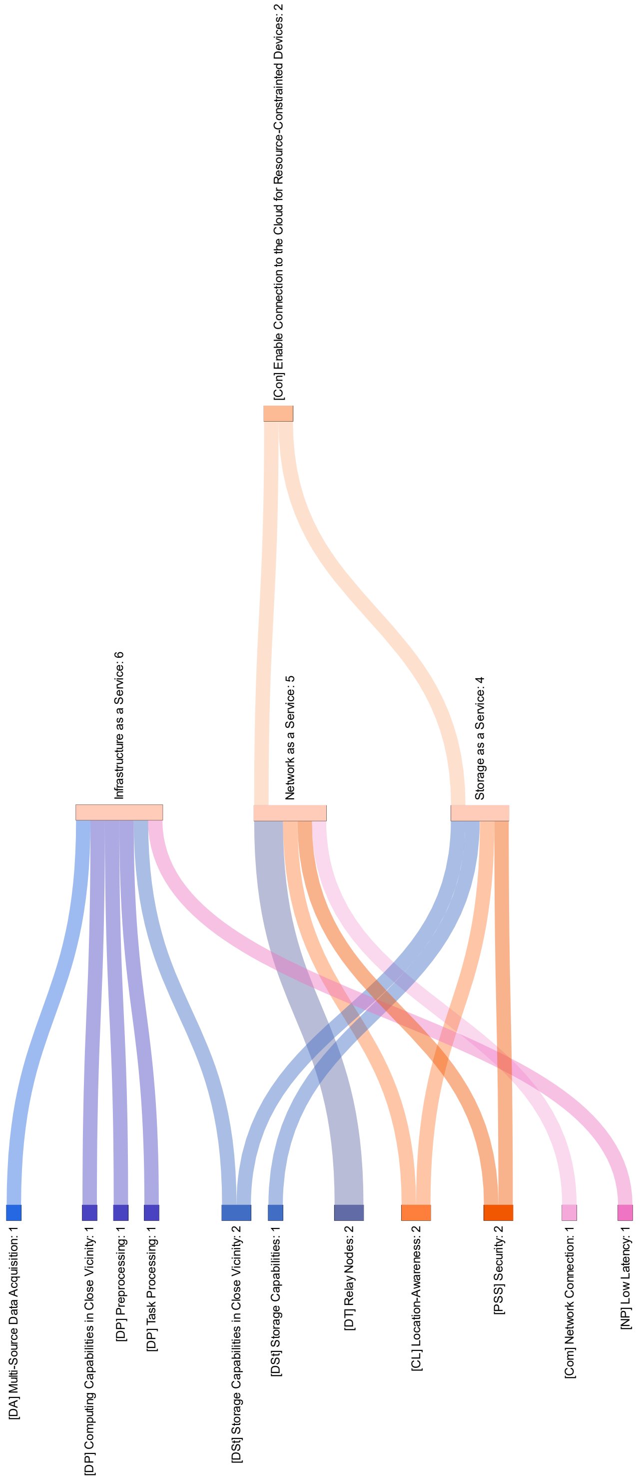


Figure 14: Color-coded and thematically grouped connection flows for the BVCS05

A large portion of IaaS connections have their origin in the *data processing* theme, indicating that even though computing power was not recovered as a service for IaaS during the TA, infrastructure as a service encompasses these. However, it should not go unmentioned, that all connections for this theme have only weak numbers support in general.

The only business value enabled by “IaaS” services is *connectivity*. More precisely, FC’s Network as a Service’ and Storage as a service can be used to enable connection to the cloud for resource-constrained devices (Cha et al., 2018, pp. 8–9).

BVCS06: Relying on FCs’ *data acquisition, data processing, contextuality & locality*, and *network properties* affordances to provide *latency-related services* for *privacy, security & transparency* and *time* business values.

BVCS06 relies on already explored affordance themes for *latency-related* services. However, in contrast to BVCS02 they are used to provide the “border-values” captured by the themes *privacy, security & transparency* and *time*. Figure 15 depicts the BVCS and its connections.

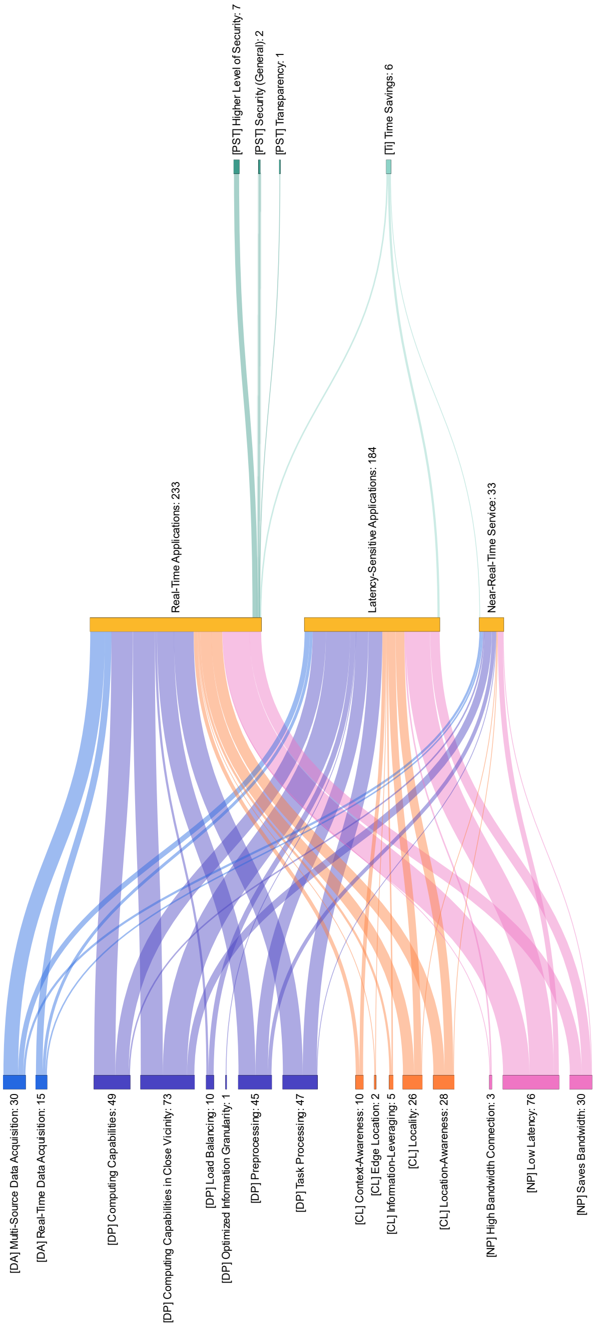


Figure 15: Color-coded and thematically grouped connection flows for the BVCS06

As already mentioned, the affordances for *latency-related services* are already described in BVCS02. Such services can, however, be used for other than the *business optimization* business values captured in BVCS02.

Latency-related services can be employed to achieve *privacy, security & transparency* business values. “Greater Security [and] increased transparency” (Hernández-Nieves et al., 2020, p. 2) can, for example, be achieved by FinTech organizations when relying on real-time applications. Higher level of security is also discussed and empirically investigated by H. Zhang et al. (2020) for their real-time smart grid encryption-as-a-service architecture, concluding that FC can aid in reaching a higher level of security or provide security (general) at least on the same level as CC architectures do (H. Zhang et al., 2020, p. 665).

All three services can be used for time savings. This is mainly observed for the medical domain. Here, medical organizations, as well as their patients can save time by using *latency-related services* to provide medical services in a way that patients do only need to come visit the doctor’s physically in case of an emergency (Beri et al., 2022, p. 7610).

Time savings are also present in the storage and processing of health information (Ilyas et al., 2022, p. 6). Furthermore, accident victims can be rescued with less delay by relying on FC (Dar et al., 2018, p. 5), saving precious time for both emergency response teams and the accident victims.

BVCS07: Relying on FCs’ *data acquisition, data processing, data storage, data transmission, contextuality & locality*, and *network properties* affordances to provide *data-related services* for *society and sustainability* business values.

BVCS07 also makes use of already investigated services. *Data-related services* (see BVCS01) can also be employed to achieve *societal* and *sustainability* business values. Figure 16 provides an overview of the BVCS and the connections within it.

As *data-related services* have been already discussed for BVCS01 above, the connections between affordances and services for these are already investigated. However, *data-related services* can also be employed for business values other than “internal values” from the *business optimization* and *financial* themes.

Data-intensive services are reported to have connections with the “external values” themes *society* and *sustainability*. For data statistics and analysis no such connections were found in the reviewed literature. The usage of FC for data-intensive services allows for increased health/wellbeing, by, for example, air quality surveillance in smart ambient applications and alerting people when the air quality reduces (e.g., too high levels of CO2 concentration) reducing distressful situations (Cerina et al., 2017, pp. 3–4).

Furthermore, societal safety can be a goal to reach for by using data-intensive services. This is reported for the smart grid domain to reduce power outages by smart scheduling of power consumption (Chouikhi et al., 2019, pp. 1817, 1820) and smart infrastructure domain by ensuring project safety for large projects of societal importance (e.g., Chinese south-north water transfer project for water conservancy (see Fan et al. (2018))).

For *sustainability*, I find, that data-intensive services can support sustainable practices and reduced energy consumption (see Cha et al. (2018)). Especially the first of which is thoroughly discussed in the reviewed literature. External road observer FNs can for example lead to safe inclusion of slow and environmentally friendly traffic participants (e.g., bikes, e-bikes) into existing traffic scenarios (Maheswaran et al., 2019, p. 3), fostering the usage of such personal transportation and mobility modes.

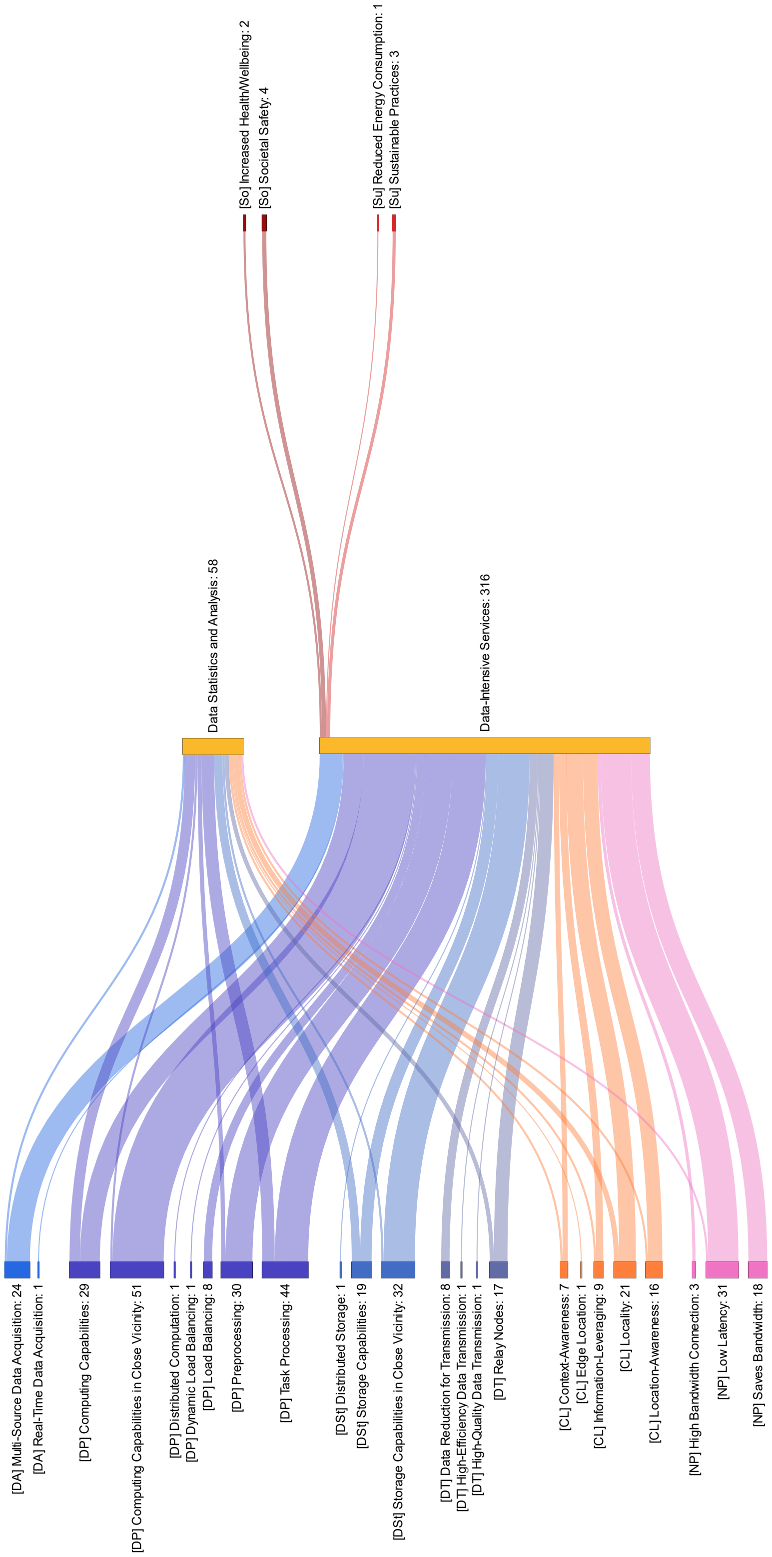


Figure 16. Color-coded and thematically grouped connection flows for the BVCS07

Moreover, traffic congestions and car accidents can be reduced by relying on FC for traffic management (Huang et al., 2017, p. 107), saving natural resource for driving and vehicle replacement/repair.

BVCS08: Relying on FCs’ *data acquisition*, *data processing*, *contextuality & locality*, and *network properties* affordances to provide *latency-related services* for *society and sustainability* business values.

Having a look at *latency-related services*, it can be observed, that also such services can be used to reach *society* and *sustainability* business values. Figure 17 provides an overview of the BVCS describing this. The relationship between affordances and services is already described in BVCS02.

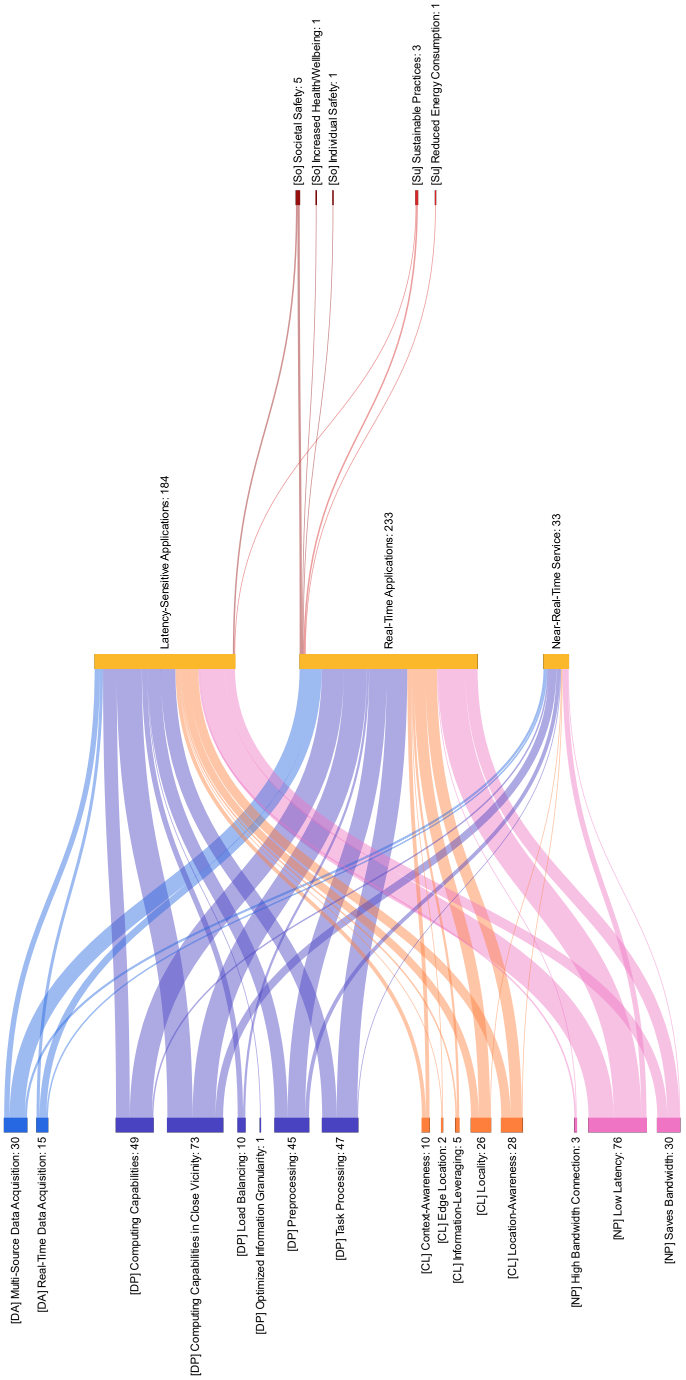


Figure 17: Color-coded and thematically grouped connection flows for the BVCS08

Latency-related services can be used for sustainable practices and reduced energy consumption. This can be observed from the same instances as already described for BVCS07, indicating, that different service types can be used in combination with one another to achieve business goals and do not need to be considered separately. For example, data-intensive real-time applications seem to allow for sustainable practices (Huang et al., 2017, p. 107; Maheswaran et al., 2019, p. 3) and reduced energy consumption (Cha et al., 2018).

This can also be observed for societal safety, where real-time applications can be used alongside data-intensive services (e.g., in smart grid settings (see Chouikhi et al. (2019)) or smart infrastructure projects (see Fan et al. (2018)). However, real-time applications can be used without data-intensive services, for example, to locally detect anomalies in households to mitigate hazards for the power grid (Jaiswal et al., 2020, pp. 1–3).

Furthermore, increased health/wellbeing of people (Cerina et al., 2017, pp. 3–4) and individual safety of traffic participants (Huang et al., 2017, p. 106) can be achieved by relying on *latency-related services* based on FC.

5. Discussion

5.1. Principal Findings

Having conducted a literature review and TA, I find that FC provides actors, such as organizations, with several affordances to reach desired goals.

First, I derive 61 affordances clustered in 4 top-level themes that range from “data” over “network” to “fog system properties”. While I recover each of the FC essential characteristics as described by Iorga et al. (2018, pp. 3–4), I find that some of these are more extensively discussed (e.g. bandwidth savings, low latency, context-awareness/location-awareness) than others (e.g. heterogeneity and interoperability). This may be due to the fact that network and performance properties can be more easily discussed and empirically validated and thus provide more room for extensive discussion. However, it may also be the case that especially these characteristics are the main reasons why FC is chosen over other computing paradigms. Furthermore, other characteristics described in related research (e.g., energy efficiency and security (Blume et al., 2022), or mobility support (Das & Inuwa, 2023)) are found during the TA, keeping the findings on affordances in line with already existing research on FC capabilities.

Second, I derive several service themes and cluster them according to generally observable service models (IaaS, PaaS, and SaaS). My findings are in line with those already described in literature, as, for example, Abdali et al. (2021) also find real-time services and near-real-time applications of FC. However, I go beyond that and provide a broader range of potential services. I also do not rely on specifically describing certain use cases but move towards identifying the overarching kinds of services used in these. No other collection of service types found in related research was found to be similarly extensive.

Third, I provide business values that represent the goals organizations want to achieve by relying on FC. I find and present four top-level themes here. FC can be used to achieve “Internal Values” of an organization, and aid *business optimization*, *business enhancement*, and *financial* goals. However, the usage of FC architectures by organizations such as medical facilities or municipal/governmental actors or organizations whose services are closely intertwined with broad societal interests, such as smart grid, urban infrastructure, or mobility (e.g., VFC), may also lead to goals outside of an organization itself. Here I can find business values related to the *society* and *sustainability*, such as societal safety or reduced energy consumption. Some of the business values, such as privacy or time savings can aid both, organizations’ internal goals and external ones. Tying back to the research question, the description of business value themes uncovers, that FC can lead to new business value creation (e.g., business values of sub-level one theme *business models / enhancement*) or can enhance existing value creation, by, for example, *business optimization*, *financial*, or *privacy, security & transparency* business values. Furthermore, not only organizations, but broader *society* and the environment (via enhanced *sustainability*) can benefit from FC.

I, furthermore, set out to uncover relationships between affordances, the services that can be built by relying on those affordances and the business values that may be achieved in doing so, in the form of BVCS. Here I especially want to highlight that, in line with literatures supposition (Hussain & Beg, 2019, p. 15), most business value creation is achieved via SaaS services. However, there are two BVCSs (BVCS04, BVCS05) that are concerned with PaaS and IaaS services.

Related to the main foal of this work, I find BVCSs, showing which FC affordances and services can be used for business values, especially in the business value themes *business optimization*, *financial*, *sustainability*, and *society*, which are related to the possibility for organizations to enhance their business value creation. However, novel business value creation is not reflected in the BVCSs, as the importance of the business value theme *business models / enhancement* does only play a minor role for any of the services described in literature.

5.2. Implication for Research and Practice

The implications of this work for research and practice are manifold.

By identifying affordances, services, and business values, by adopting an affordance theory as a lens, I elevate the current discussion on FC from a theoretical perspective to a more organization-centric one. My work can aid organizations that currently wonder whether FC may be suitable for their goals and service setting in coming to a decision, by taking the BVCSs into consideration and comparing these to their situation. Organizations that are interested in, for example, optimizing their business’s value creation, can have a look at BVCS01 – BVCS04 to find suitable SaaS or PaaS services they may employ by relying on the FC affordances described for these services and depending on their concrete situation.

Looking at research implications, I enhance knowledge on FC affordances, services and business values. For example, I identify and describe 12 different service types FSs are used for, whereas former literature on FC services only inferred three service types (see Abdali et al. (2021)). Moreover, I provide a stepping stone for future research on FC affordances and business values, that goes beyond the current literatures discussion of capabilities and application scenarios and opens up new research avenues. As it became visible, that FC is currently not extensively discussed for novel business value creation, this work further identifies gaps in current research, worth investigating.

This work, further, is the first that extensively discusses potential business values of FC for organizations. In line with findings on business value creation streams from the domain of FC in IoT (Perifanis & Kitsios, 2022, pp. 15–17), I find business values of *business optimization* and identify monetization (in form of *financial* business values) as important. Furthermore, as FC, as well as the domain of IoT, involves multiple stakeholders, and although this work was conducted with focus on organizations themselves, I find that FC also generates business values outside of the organizations themselves. However, the similarities in business values is not surprising, as IoT-related papers make up a large portion of the literature that is included in this work. This work is shifting the IoT centric point of view employed by Perifanis and Kitsios (2022), seeing FC only as lever to enhance IoT capabilities, to focusing on FC as a technology directly and without limiting the domain of application, extending research knowledge on FC.

The identification of BVCSs enables for a more precise academic discussion on how FC can aid organizations in their endeavor to create value. They show that by doing so not only organizational business values can be achieved, but also values for society and environment can be created. This work thus serves, once more, as a basis for future academic research and discussion in the field.

5.3. Limitations

However, this work does not come without limitations, most of which have their origin in the literature review process itself.

First of all, no forward and backward search have been conducted on the 58 articles included in the review. Thus, I may miss out on relevant pieces of literature that have not been discovered by the search on the databases directly, which may hold further potential affordances, services or business values and could extend the breadth or depth of this review. Similarly, the sources of other literature reviews uncovered in the literature search have not been studied separately. As the reviews were deemed relevant and related, their sources may hold valuable further insights or possibilities to support currently weak supported codes and themes. However, it seems as if the current set of literature is sufficient to reach theoretical saturation to a certain degree, as the vast majority of affordances and business values and all services have been uncovered already in the first half of the literature analysis, mitigating these limitations to some extent.

Moreover, even though the search string was quite extensive, the decision to include or exclude certain search terms was made based on one of the six databases included. Thus, search terms potentially yielding hits on other databases may have been not included in the search string. Further, extending the search terms by more possible synonyms or other terms related to them could have yielded more hits and thus potentially more relevant publications. This is worsened, by not having performed a forward or backward step, as described above.

The last limitation arising from the review process is concerning the peer review status of the literature found during search. At first, no peer review filters were applied. Concerned, that this might diminish the quality of publications in the review the search was checked with peer-review filter in, where possible. For *EBSCOhost*, using the peer-review filter revealed, two reports not peer reviewed (and one duplicate non-peer reviewed hit). Both were not used in the review, as one could not be retrieved, and the other one was excluded as news article on a technology standard. *IEEE Xplore* journal and conference publications are described as being peer reviewed (IEEE, n.d.–a, n.d.–b), as well as the included IEEE magazine publications (IEEE Communications Society, n.d., 2023). Also *Science Direct* reports their data base search yielding only peer reviewed publications on their search front page. The conference preprint was later published in ACM DL, which is also peer reviewed (ACM, 2022).

Applying a peer-review filter for ProQuest, yields only 27 instead of 45 hits, thus having only peer-reviewed articles in the literature search process would have made a significant impact on the numbers reported in section 3.1. Checking the peer review status of each of the 58 publications in the review reveals that only two publications could not be directly found as peer reviewed within data bases or respective peer reviewed conferences and journals. These two are X. Zhu et al. (2015), published in the Intel Technology Journal and Knebel et al. (2021), being the journal preprint. The Intel Technology Journal was reported to be a peer reviewed technical journal (Cohen, 2012) to be peer reviewed in the past, even though no more credible source could be found for that statement. The journal preprint was submitted to the Journal of Internet Services and Applications, published by SpringerOpen, that would have been peer-reviewed (SpringerOpen, n.d.). However, no status update on that has been published by Knebel et al. (2021). Summarizing the above, all publications in the review ended up either peer reviewed, or with weak indication for being peer reviewed to certain extend. However, the inclusion of the two not surely peer-reviewed publications may limit the impact and credibility of the findings of this review.

Furthermore, the literature analysis and coding, as well as the TA have been performed by only one coder, potentially inducing subjective bias and limiting the findings to the thoughts of one researcher only. No validation of the identified themes or BVCSs has been performed, limiting the impact of this work.

Another limitation arises from the TA. As affordances only arise from the combination of actors, technologies and the actors' goals, more focus on possible actors is necessary. The current analysis is based on identifying affordances for organizations in general. A sufficient analysis of actors and their relationship to the affordances could uncover more insights and provide further valuable guidance for organizations and other stakeholders involved.

Furthermore, some of the (affordance) codes are only supported by one text passage, limiting their meaningfulness. However, themes are always supported by more than one text passage and thus provide a better level of abstraction.

5.4. Future Research Opportunities

As I see this work as a steppingstone towards a broader discussion of FC's value for organizations, I want to elaborate on some opportunities for future research:

As this work uncovered, that the current academic discussion on FC does not see extensive possibilities for novel value creation paths, future work should set out to seek and identify such novel value creation opportunities.

The identified BVCSs can further be used as an opportunity to investigate one or several BVCSs in more detail and with involvement of organizations from industry or state institutions. Further, future research could and should investigate how the BVCSs change for different domains, to identify stable BVCSs that can be applied to several domains or BVCSs special to certain domains. Furthermore, this could enable a discussion on which business values are achieved by certain combinations of services, that are currently only considered separate from one another.

More future research opportunities arise from the limitations of this work. Future research may overcome these by incorporating more articles in the review (e.g., by performing a forward/backward search on this reviews literature set, using the literature the identified literature reviews are based upon, including the 31 papers excluded for only having weak focus in the screening step) or by shifting the focus of this work towards FC architectures employed in practice.

Another opportunity to overcome limitations may be a more thorough discussion of potential actors (e.g., end users, organizations stake holders, FC system providers, network providers, etc.) and more focused considerations of affordances and business values FC may provide to each of these potential actors. Like this, for example, the business value themes for society and environment could be extended.

6. Conclusion

This work set out to answer the research question of "*How can fog computing create or enhance business value for an organization?*". By conducting a literature review of six databases and including 58 articles in the review, I derived 61 FC affordances, 12 services and 32 business values. These were then grouped into themes by performing a TA for further discussion and presentation. Based on these themes eight BVCSs have been created, showcasing how certain affordances can aid specific services to achieve business values for an organization. To the best of my knowledge, this work is the first to adopt an affordance theory lens for identifying the potential value of FC. I see my work as steppingstone for both research and practice to further elaborate on the potential value that FC can bring and affordances it provides. For doing so I provide future research opportunities and reflect the own work critically.

Appendix

A. Publications Included in the Review

Table 20: Overview of publications included in the review

ID	Autor (Year)	Titel	Publication Type	Domain Category	Method	Validation Type
7	Mayer et al. (2021)	FogChain: A Fog Computing Architecture Integrating Blockchain and Internet of Things for Personal Health Records	J	Medical / Healthcare	Arch	LE
14	Soua and Tohme (2018)	Multi-level SDN with Vehicles as Fog Computing Infrastructures: A new Integrated Architecture for 5G-VANETs	C	VFC	Arch	PoC
19	Alghamdi et al. (2019)	A Novel Fog Computing Based Architecture to Improve the Performance in Content Delivery Networks	J	Content Delivery	Arch	S
29	Dar et al. (2018)	An Architecture for Fog Computing Enabled Emergency Response and Disaster Management System (ERDMS)	C	Special Use Cases	Arch	NO
32	Beri et al. (2022)	A Novel Fog-computing-assisted Architecture of E-healthcare System for Pregnant Women	J	Medical / Healthcare	Arch	P
36	Cha et al. (2018)	A Study on the Design of Fog Computing Architecture Using Sensor Networks	J	FC and IoT	Arch	S
37	S. Chang et al. (2020)	Smart Grid Data Security Aggregation Method Based on Fog Computing Architecture for Integrated Energy Services	C	Smart Infra. & Agri.	Alg	U
53	Fan et al. (2018)	Cloud/Fog Computing System Architecture and Key Technologies for South-North Water Transfer Project Safety	J	Smart Infra. & Agri.	Arch	NO
56	Knebel et al. (2021)	A Cloud-Fog Computing Architecture for Real-Time Digital Twins	JP	Special Use Cases	Arch	LE
66	Du et al. (2020)	A New Vehicular Fog Computing Architecture for Cooperative Sensing of Autonomous Driving	J	VFC	Arch	S
73	H. Zhang et al. (2020)	An Adaptive Encryption-as-a-Service Architecture Based on Fog Computing for Real-Time Substation Communications	J	Smart Infra. & Agri.	Arch	LE
74	Hassan et al. (2020)	Remote Pain Monitoring Using Fog Computing for e-Healthcare: An Efficient Architecture	J	Medical / Healthcare	Arch	S
75	Hernández-Nieves et al. (2020)	Fog Computing Architecture for Personalized Recommendation of Banking Products	J	Finance and Industry	Arch	NO
77	Huang et al. (2017)	Vehicular Fog Computing: Architecture, Use Case, and Security and Forensic Challenges	M	VFC	Arch	NO
80	Ilyas et al. (2022)	Software Architecture for Pervasive Critical Health Monitoring System Using Fog Computing	J	Medical / Healthcare	Arch	S
86	Santos et al. (2021)	SRFog: A Flexible Architecture for Virtual Reality Content Delivery through Fog Computing and Segment Routing	C	FC (General)	Arch	PoC

ID	Autor (Year)	Titel	Publication Type	Domain Category	Method	Validation Type
89	J. Zhu et al. (2013)	Improving Web Sites Performance Using Edge Servers in Fog Computing Architecture	C	Content Delivery	Arch	NO
90	Jalowiczor et al. (2021)	Study of the Efficiency of Fog Computing in an Optimized LoRaWAN Cloud Architecture	J	FC and IoT	Arch	LE
102	Cerina et al. (2017)	A Fog-computing Architecture for Preventive Healthcare and Assisted Living in Smart Ambients	C	Medical / Healthcare	Arch	P
105	Vega et al. (2018)	A Peer-to-Peer Architecture for Distributed Data Monetization in Fog Computing Scenarios	J	FC (General)	Arch	PoC
110	Alam et al. (2021)	ioFog: Prediction-based Fog Computing Architecture for Offline IoT	C	FC and IoT	Arch	S
121	Maheswaran et al. (2019)	A Fog Computing Framework for Autonomous Driving Assist: Architecture, Experiments, and Challenges	CP	VFC	Arch	LE
122	Mai (2019)	Research on Internet of Things Security Architecture Based on Fog Computing	J	FC (General)	Arch	NO
126	Hussain and Beg (2019)	Fog Computing for Internet of Things (IoT)-Aided Smart Grid Architectures	J	Smart Infra. & Agri.	Arch	S
127	Muneeb et al. (2021)	A Fog Computing Architecture with Multi-Layer for Computing-Intensive IoT Applications	J	FC and IoT	Arch	S
129	Khumalo et al. (2019)	Fog Computing Architecture for 5G-Compliant IoT Applications in Underserved Communities	C	FC and IoT	Arch	S
131	Nadeem et al. (2019)	Securing Cognitive Radio Vehicular Ad Hoc Network with Fog Node based Distributed Blockchain Cloud Architecture	J	VFC	Arch	NO
138	Nurnoby and Helmy (2023)	A Real-Time Deep Learning-based Smart Surveillance Using Fog Computing: A Complete Architecture	C	Audio and Video	Arch	LE
139	Battistoni et al. (2019)	Experimenting with a Fog-computing Architecture for Indoor Navigation	C	FC (General)	Arch	PoC
140	Fraga-Lamas et al. (2020)	Design and Empirical Validation of a Bluetooth 5 Fog Computing Based Industrial CPS Architecture for Intelligent Industry 4.0 Shipyard Workshops	J	Finance and Industry	Arch	P
146	P. Wang et al. (2018)	A Cross-Age Face Recognition Approach Using Fog Computing Architecture for User Authentication on Mobile Devices	C	Audio and Video	Arch	LE
147	Pecori (2018)	A Virtual Learning Architecture Enhanced by Fog Computing and Big Data Streams	J	Special Use Cases	Arch	P
150	Priyadarshini et al. (2018)	*DeepFog*: Fog Computing-Based Deep Neural Architecture for Prediction of Stress Types, Diabetes and Hypertension Attacks	J	Medical / Healthcare	Arch	LE
153	Brzoza-Woch et al. (2016)	Embedded Systems in the Application of Fog Computing — Levee Monitoring Use Case	C	Special Use Cases	Arch	P
155	Jaiswal et al. (2020)	Distributed Fog Computing Architecture for Real-Time Anomaly Detection in Smart Meter Data	C	Smart Infra. & Agri.	Arch	LE
159	Rampérez et al. (2018)	A Multidomain Standards-Based Fog Computing Architecture for Smart Cities	J	Smart City	Arch	P

ID	Autor (Year)	Titel	Publication Type	Domain Category	Method	Validation Type
161	Cao et al. (2019)	Space-Based Cloud-Fog Computing Architecture and its Applications	C	Special Use Cases	Arch	S
162	Chouikhi et al. (2019)	A Fog Computing Architecture for Energy Demand Scheduling in Smart Grid	C	Smart Infra. & Agri.	Arch	S
163	Chun et al. (2016)	A Pub/Sub-Based Fog Computing Architecture for Internet-of-Vehicles	C	VFC	Arch	NO
168	Mirzaie et al. (2021)	Anomaly Detection in Urban Water Distribution Grids Using Fog Computing Architecture	C	Smart City	Arch	LE
171	S. Singh et al. (2016)	Mobile Edge Fog Computing in 5G Era: Architecture and Implementation	C	Special Use Cases	Arch	P
172	Tahmasebi et al. (2020)	A Scalable Architecture for Monitoring IoT Devices Using Ethereum and Fog Computing	C	FC and IoT	Arch	LE
177	Silva et al. (2019)	A Fog Computing-Based Architecture for Medical Records Management	J	Medical / Healthcare	Arch	P
182	Hewa et al. (2022)	Fog Computing and Blockchain-Based Security Service Architecture for 5G Industrial IoT-Enabled Cloud Manufacturing	J	Finance and Industry	Arch	LE
183	Mekki et al. (2018)	Towards Multi-Access Edge Based Vehicular Fog Computing Architecture	C	VFC	Arch	S
188	Tsipis et al. (2020)	Latency-Adjustable Cloud/Fog Computing Architecture for Time-Sensitive Environmental Monitoring in Olive Groves	J	Smart Infra. & Agri.	Arch	P
190	Karagiannis and Schulte (2020)	Comparison of Alternative Architectures in Fog Computing	C	FC (General)	Arch	S
192	Mihai et al. (2018)	Wireless Sensor Network Architecture based on Fog Computing	C	FC and IoT	Arch	P
195	W. Chen et al. (2019)	Pitch DBN Based Audio Search with Fog Computing Architecture	C	Audio and Video	Arch	LE
196	Ji et al. (2020)	Crowd V-IoE: Visual Internet of Everything Architecture in AI-Driven Fog Computing	J	Audio and Video	Arch	LE
200	Zheng et al. (2020)	Fog Computing Enabled Smart Grid Blockchain Architecture and Performance Optimization with DRL Approach	C	Smart Infra. & Agri.	Arch	S
203	Wei and Wu (2019)	A New Proposed Sensor Cloud Architecture Based on Fog Computing for Internet of Things	C	FC and IoT	Arch	NO
205	X. Zhu et al. (2015)	Improving Video Performance with Edge Servers in the Fog Computing Architecture	J	Audio and Video	Arch	LE
209	Liu et al. (2017)	A Framework of Fog Computing: Architecture, Challenges, and Optimization	J	FC and IoT	Arch	S
210	Luo et al. (2021)	Energy Efficient Fog Computing with Architecture of Smart Traffic Lights System	C	Smart City	Arch	S
216	Constantinescu and Vladoiu (2020)	Towards Vehicular Fog Computing: An Architecture for Connected Vehicles and Vehicular Clouds	C	VFC	Arch	P

ID	Autor (Year)	Titel	Publication Type	Domain Category	Method	Validation Type
220	W. Zhang et al. (2017)	Cooperative Fog Computing for Dealing with Big Data in the Internet of Vehicles: Architecture and Hierarchical Resource Management	M	VFC	Arch	S
225	C. Zhu et al. (2022)	Software-Defined Maritime Fog Computing: Architecture, Advantages, and Feasibility	J	Special Use Cases	Arch	S

Legend:

Publication Type:	J = Journal Article, C = Conference Article, JP = Journal Preprint, CP = Conference Preprint, M = Magazine Article;
Method:	Alg = Algorithm Design, Arch = Architecture Design;
Validation Type:	LE = Laboratory Experiment, NO = No Validation, P = Prototype Study, PoC = Proof of Concept Study, S = Simulation, U = Unclear Validation;

B. Thematic Maps for Affordance, Service, and Business Value Themes after 50% of Reviewed Publications

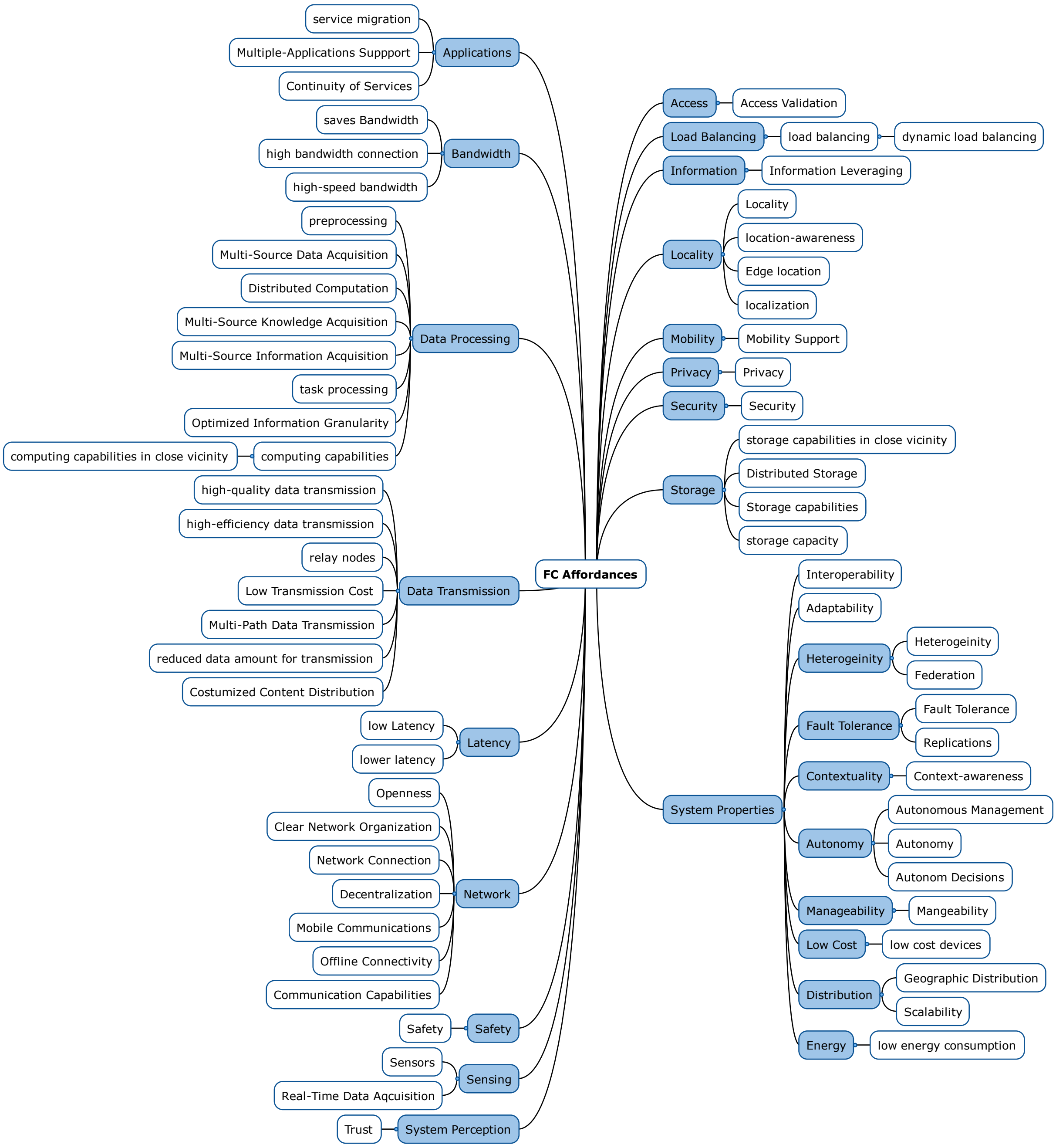


Figure 18: Thematic map of FC affordances after 50% of publications included in the TA

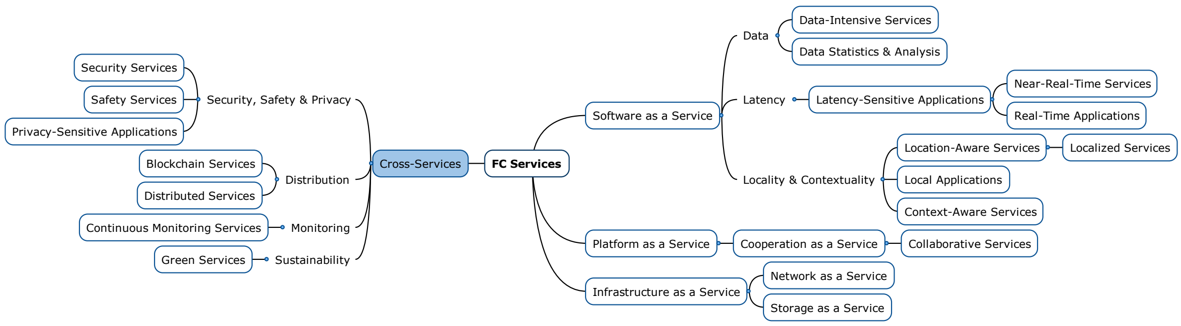


Figure 19: Thematic map of FC services after 50% of publications in the TA

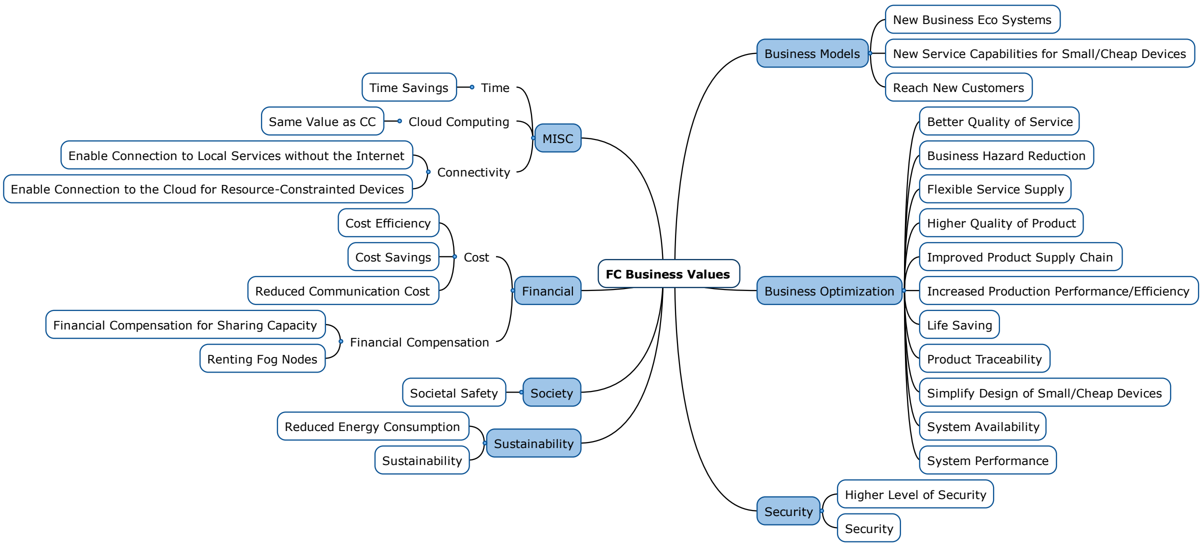


Figure 20: Thematic map of FC business values after 50% of publications in the TA

C. Thematic Map of FC Affordance Themes

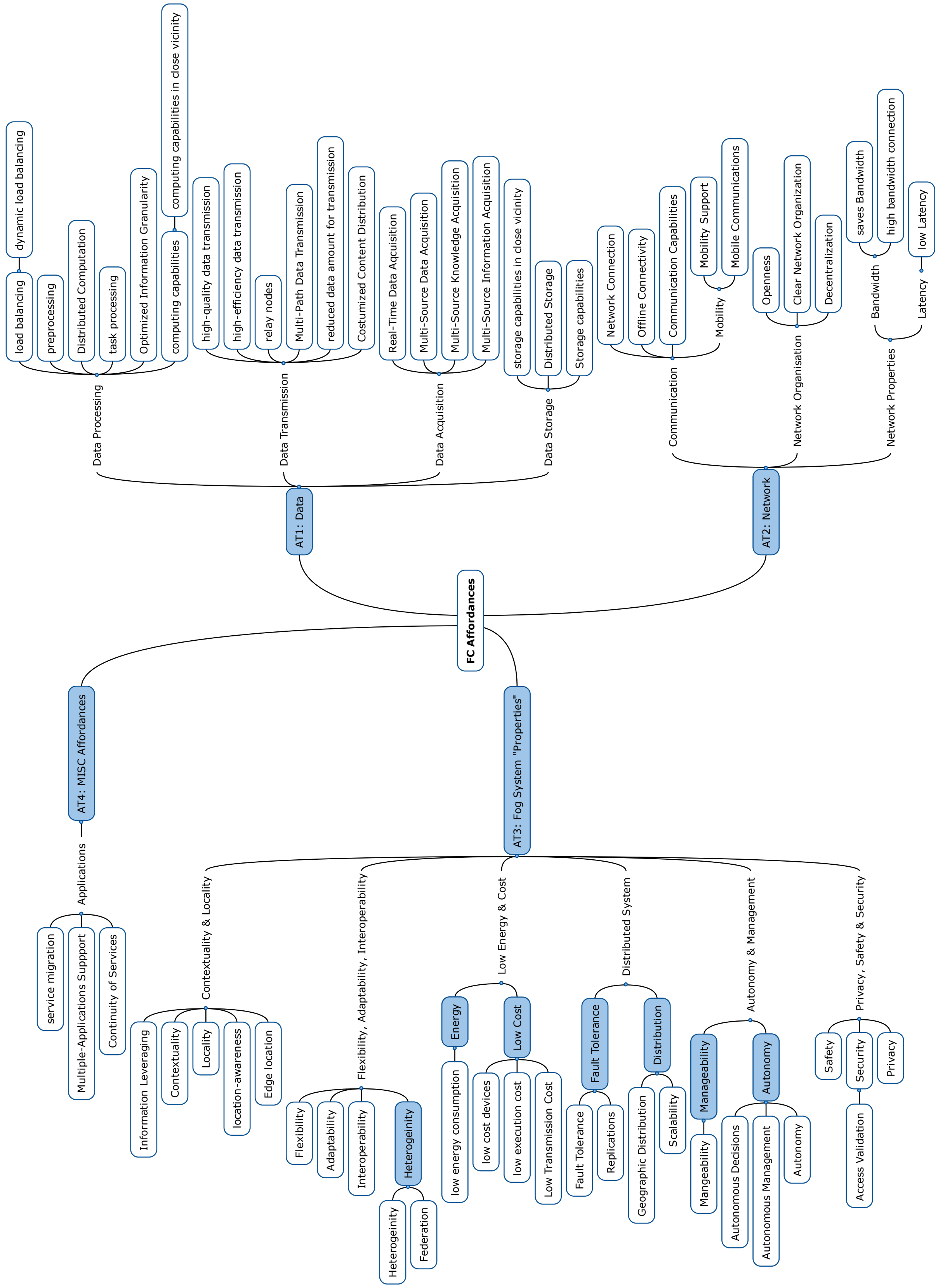


Figure 21: Thematic map of FC affordances

D. Publications’ Contributions to Affordance, Business Value, and Service Themes

Table 21: Affordance, business values, and service themes identified for each publication included in the review

ID	Affordance														Business Value									Service					
	Data				Fog System Properties						MISC	Network			Border Values		External Values		Internal Values			MISC		IaaS	PaaS	SaaS			
	Data Acquisition	Data Processing	Data Storage	Data Transmission	Autonomy & Management	Contextuality & Locality	Distributed System	Flexibility, Adaptability, Interoperability	Low Energy & Cost	Privacy, Safety & Security	Applications	Communication	Network Organization	Network Properties	Privacy, Security & Transparency	Time	Society	Sustainability	Business Models / Enhancement	Business Optimization	Financial	Cloud Computing	Connectivity	Infrastructure as a Service	Platform as a Service	Data	Latency	Locality & Contextuality	Software as a Service
7	X	X	X			X	X	X				X		X						X							X	X	
14	X	X	X	X	X	X	X					X		X						X	X				X		X		
19			X			X						X		X						X					X			X	
29	X	X				X			X					X		X				X	X								
32	X	X								X						X				X	X						X		
36	X	X	X	X		X	X			X		X		X				X					X	X		X	X		
37	X	X	X	X					X					X	X					X							X		
53	X	X	X			X	X					X		X			X			X						X	X		
56	X	X	X	X							X			X						X							X		
66	X	X			X							X				X	X			X					X				
73	X	X	X		X	X		X		X		X		X	X					X							X		
74	X	X	X	X		X	X	X	X					X		X				X						X	X		
75	X	X	X			X						X			X					X	X						X		
77	X	X	X	X	X	X						X		X			X	X		X						X	X		
80	X	X	X	X	X	X								X		X				X						X	X		
86		X	X				X				X	X		X						X							X		
89		X	X			X								X						X	X					X			
90		X	X	X		X				X		X														X			
102	X	X		X	X	X	X		X	X		X		X			X			X						X	X		
105	X	X	X			X	X	X		X		X			X						X					X		X	
110		X	X		X	X						X		X						X								X	
121	X	X				X	X							X				X		X						X	X	X	
122	X	X	X			X		X		X		X		X							X	X				X	X		
126	X	X	X			X	X		X			X		X						X						X	X	X	X
127	X	X	X	X		X	X					X		X												X	X	X	
129	X	X	X		X	X	X	X		X		X		X				X		X	X								
131		X	X			X				X				X					X							X			

	Affordance														Business Value									Service					
	Data				Fog System Properties						MISC	Network			Border Values		External Values		Internal Values			MISC		IaaS	PaaS	SaaS			
ID	Data Acquisition	Data Processing	Data Storage	Data Transmission	Autonomy & Management	Contextuality & Locality	Distributed System	Flexibility, Adaptability, Interoperability	Low Energy & Cost	Privacy, Safety & Security	Applications	Communication	Network Organization	Network Properties	Privacy, Security & Transparency	Time	Society	Sustainability	Business Models / Enhancement	Business Optimization	Financial	Cloud Computing	Connectivity	Infrastructure as a Service	Platform as a Service	Data	Latency	Locality & Contextuality	Software as a Service
138	X	X	X				X				X			X												X	X		
139	X		X	X	X		X	X	X			X		X										X			X	X	
140		X				X	X							X						X					X		X	X	
146		X	X			X																					X	X	
147	X	X	X		X									X						X				X	X	X			X
150	X	X																		X						X			
153	X	X		X	X	X		X	X					X						X								X	
155	X	X				X	X							X			X				X						X		
159	X	X				X	X	X					X	X						X							X	X	
161		X	X	X	X	X		X			X			X					X	X			X		X	X	X		
162		X		X	X		X							X			X			X	X					X	X		
163		X				X	X							X													X	X	
168		X	X			X								X			X				X					X	X		
171		X	X	X								X	X	X					X	X								X	
172		X	X	X			X						X								X							X	
177			X		X		X	X		X			X	X						X							X	X	
182		X	X	X			X			X			X	X													X	X	
183		X	X	X	X	X								X					X	X	X			X		X		X	
188		X		X	X	X	X		X	X				X						X	X					X	X	X	
190		X												X													X		
192		X			X																					X			
195	X	X	X			X				X			X													X	X		
196		X	X			X		X	X			X	X	X						X				X		X	X		
200		X	X			X																						X	
203		X	X											X													X	X	
205		X	X			X	X	X			X	X		X	X					X	X					X	X	X	
209		X												X												X	X		
210		X							X									X		X	X						X		
216	X	X	X		X	X		X		X						X		X	X		X		X	X	X	X	X	X	
220	X	X	X	X	X	X						X	X	X												X			
225		X	X	X										X	X				X				X			X	X	X	

References

Aazam, M., Zeadally, S., & Harras, K. A. (2018). Fog computing architecture, evaluation, and future research directions. *IEEE Communications Magazine, 56*(5), 46–52. https://doi.org/10.1109/MCOM.2018.1700707

Abdali, T.-A. N., Hassan, R., Aman, A. H. M., & Nguyen, Q. N. (2021). Fog computing advancement: Concept, architecture, applications, advantages, and open issues. *IEEE Access*, *9*, 75961–75980. https://doi.org/10.1109/ACCESS.2021.3081770

Abuseta, Y. (2019). A fog computing based architecture for IoT services and applications development. *International Journal of Computer Trends and Technology (IJCTT), 67*(10), 92–98. https://doi.org/10.14445/22312803/IJCTT-V67I10P116

ACM. (2022). *ACM Peer Review Policy*. ACM. https://www.acm.org/publications/policies/peer-review#:~:text=The%20form%20of%20reviewing%20for,is%20single%2Danonymous%20peer%20review.

Alam, M., Ahmed, N., Matam, R., & Barbhuiya, F. A. (2021). ioFog: Prediction-based fog computing architecture for offline IoT. In *2021 International Wireless Communications and Mobile Computing (IWCMC)* (pp. 1387–1392). IEEE. https://doi.org/10.1109/IWCMC51323.2021.9498796

Alghamdi, F., Mahfoudh, S., Barnawi, A., & Miguel Garcia-Pineda (2019). A novel fog computing based architecture to improve the performance in content delivery networks. *Wireless Communications & Mobile Computing, 2019,* Article 7864094. https://doi.org/10.1155/2019/7864094

Antonini, M., Vecchio, M., & Antonelli, F. (2019). Fog computing architectures: A reference for practitioners. *IEEE Internet of Things Magazine, 2*(3), 19–25. https://doi.org/10.1109/IOTM.0001.1900029

Battistoni, P., Sebillo, M., & Vitiello, G. (2019). Experimenting with a fog-computing architecture for indoor navigation. In *2019 Fourth International Conference on Fog and Mobile Edge Computing (FMEC)* (pp. 161–165). IEEE. https://doi.org/10.1109/FMEC.2019.8795307

Beri, R., Dubey, M. K., Gehlot, A., Singh, R., Abd-Elnaby, M., & Singh, A. (2022). A novel fog-computing-assisted architecture of E-healthcare system for pregnant women. *Journal of Supercomputing*, *78*(6), 7591–7615. https://doi.org/10.1007/s11227-021-04176-7

Blume, M., Lins, S., & Sunvaev, A. (2022). Understanding interdependencies among fog system characteristics. In *2022 IEEE 24th Conference on Business Informatics (CBI 2022): Proceedings* (pp. 126–135). IEEE. https://doi.org/10.1109/CBI54897.2022.00021

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brdar, D. (2022). *Cloud Computing Energy's Efficiency Problems*. https://www.nasdaq.com/articles/cloud-computing-energys-efficiency-problems

Brocke, J. vom, Simons, A., Riemer, K., Niehaves, B., Plattfaut, R., & Cleven, A. (2015). Standing on the shoulders of giants: Challenges and recommendations of literature search in information systems research. *Communications of the Association for Information Systems*, *37*(1), Article 9. https://doi.org/10.17705/1CAIS.03709

Brzoza-Woch, R., Konieczny, M., Nawrocki, P., Szydlo, T., & Zielinski, K. (2016). Embedded systems in the application of fog computing — Levee monitoring use case. In *2016 11th IEEE Symposium on Industrial Embedded Systems (SIES 2016)* (pp. 1–6). IEEE. https://doi.org/10.1109/SIES.2016.7509437

Byers, C. C. (2017). Architectural imperatives for fog computing: Use cases, requirements, and architectural techniques for fog-enabled iot networks. *IEEE Communications Magazine*, *55*(8), 14–20. https://doi.org/10.1109/MCOM.2017.1600885

Caiza, G., Saeteros, M., Oñate, W., & Garcia, M. V. (2020). Fog computing at industrial level, architecture, latency, energy, and security: A review. *Heliyon*, *6*(4), Article e03706. https://doi.org/10.1016/j.heliyon.2020.e03706

Cao, S., Zhao, Y., Wei, J., Yang, S., & Yan, L. (2019). Space-based cloud-fog computing architecture and its applications. In C. K. Chang (Ed.), *2019 IEEE World Congress on Services (IEEE SERVICES 2019): Proceedings* (pp. 166–171). IEEE. https://doi.org/10.1109/SERVICES.2019.00048

Cerina, L., Notargiacomo, S., Greco, M., Paccani, L., & Santambrogio, M. D. (2017). A fog-computing architecture for preventive healthcare and assisted living in smart ambients. In *2017 IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI)* (pp. 1–6). IEEE. https://doi.org/10.1109/RTSI.2017.8065939

Cha, H.-J., Yang, H.-K., & Song, Y.-J. (2018). A study on the design of fog computing architecture using sensor networks. *Sensors*, *18*(11), Article 3633. https://doi.org/10.3390/s18113633

Chang, S., Ge, S., Yining, G., & Zhenxian, Y. (2020). Smart grid data security aggregation method based on fog computing architecture for integrated energy services. *IOP Conference Series: Earth and Environmental Science*, *512*, Article 012116. https://doi.org/10.1088/1755-1315/512/1/012116

Chen, W., Wang, D., & Li, F. (2019). Pitch DBN based audio search with fog computing architecture. In *Ieee INFOCOM 2019 - IEEE Conference on Computer Communications Workshops (INFOCOM WKSHPS)* (pp. 1–6). IEEE.

Chouikhi, S., Merghem-Boulahia, L., & Esseghir, M. (2019). A fog computing architecture for energy demand scheduling in smart grid. In *2019 15th International Wireless Communications & Monile Computing Conference (IWCMC 2019)* (pp. 1815–1821). IEEE. https://doi.org/10.1109/IWCMC.2019.8766699

Chun, S., Shin, S., Seo, S., Eom, S., Jung, J., & Lee, K.-H. (2016). A pub/sub-based fog computing architecture for Internet-of-Vehicles. In *8th IEEE International Conference on Cloud Computing Technology and Science (CloudCom 2016): Proceedings* (pp. 90–93). IEEE. https://doi.org/10.1109/CloudCom.2016.0029

Cohen, R. (2012). *Intel Technology Journal 2012: The Past, The Present, and The Future of Cloud Computing*. https://www.forbes.com/sites/reuvencohen/2012/11/19/intel-technology-journal-2012-the-past-the-present-and-the-future-of-cloud-computing/?sh=5be2490b6c86

Constantinescu, Z., & Vladoiu, M. (2020). Towards vehicular fog computing: An architecture for connected vehicles and vehicular clouds. In P. Gasner (Ed.), *2020 - 19th RoEduNet Conference: Networking in Education and Research (RoEduNet): Proceedings* (pp. 1–6). IEEE. https://doi.org/10.1109/RoEduNet51892.2020.9324868

Dar, B. K., Shah, M. A [Muanm Ali], Shahid, H., Fizzah, F., & Amjad, Z. (2018). An architecture for fog computing enabled emergency response and disaster management System (ERDMS). In X. Ma (Ed.), *2018 24th International Conference on Automation and Computing (ICAC): Improving productivity through automation and computing* (pp. 1–6). IEEE. https://doi.org/10.23919/IConAC.2018.8749064

Das, R., & Inuwa, M. M. (2023). A review on fog computing: Issues, characteristics, challenges, and potential applications. *Telematics and Informatics Reports*, *10*, Article 100049. https://doi.org/10.1016/j.teler.2023.100049

Dastjerdi, A. V., & Buyya, R. (2016). Fog computing: Helping the Internet of Things realize its potential. *Computer*, *49*(8), 112–116. https://doi.org/10.1109/MC.2016.245

Dremel, C., Herterich, M. M., Wulf, J., & Brocke, J. vom (2020). Actualizing big data analytics affordances: A revelatory case study. *Information & Management*, *57*(1), 103121. https://doi.org/10.1016/j.im.2018.10.007

Du, H., Leng, S., Wu, F., Chen, X., & Mao, S. (2020). A new vehicular fog computing architecture for cooperative sensing of autonomous driving. *IEEE Access*, *8*, 10997–11006. https://doi.org/10.1109/ACCESS.2020.2964029

Fan, Y., Zhu, Q., & Liu, Y. (2018). Cloud/fog computing system architecture and key technologies for South-North Water Transfer Project safety. *Wireless Communications & Mobile Computing*, *2018*, Article 7172045. https://doi.org/10.1155/2018/7172045

Fraga-Lamas, P., Lopez-Iturri, P., Celaya-Echarri, M., Blanco-Novoa, O., Azpilicueta, L., Varela-Barbeito, J., Falcone, F., & Fernández-Caramés, T. M. (2020). Design and empirical validation of a

Bluetooth 5 fog computing based industrial CPS architecture for intelligent Industry 4.0 shipyard workshops. *IEEE Access*, *8*, 45496–45511. https://doi.org/10.1109/ACCESS.2020.2978291

Gibson, J. J. (1977). The theory of affordances. In Bransford, R. E. S. J. (Ed.), *PERCEIVING, ACTING AND KNOWING: Toward an ecological psychology* (pp. 67–82). Lawrence Erlbaum Associates.

Gupta, H., Dastjerdi, A. V., Ghosh, S. K., & Buyya, R. (2017). iFogSim: A toolkit for modeling and simulation of resource management techniques in the Internet of Things, Edge and Fog computing environments. *Software: Practice and Experience*, *47*(9), 1275–1296. https://doi.org/10.1002/spe.2509

Habibi, P., Farhoudi, M., Kazemian, S., Khorsandi, S., & Leon-Garcia, A. (2020). Fog computing: A comprehensive architectural survey. *IEEE Access*, *8*, 69105–69133. https://doi.org/10.1109/ACCESS.2020.2983253

Haouari, F., Faraj, R., & AlJa'am, J. M. (2018). Fog computing potentials, applications, and challenges. In *2018 International Conference on Computer and Applications (ICCA)*.

Hassan, S. R., Ahmad, I., Ahmad, S., Alfaify, A., & Shafiq, M. (2020). Remote pain monitoring using fog computing for e-Healthcare: An efficient architecture. *Sensors*, *20*(22), Article 6574. https://doi.org/10.3390/s20226574

Hernández-Nieves, E., Hernández, G., Gil-González, A.-B., Rodríguez-González, S., & Corchado, J. M. (2020). Fog computing architecture for personalized recommendation of banking products. *Expert Systems with Applications*, *140*, Article 112900. https://doi.org/10.1016/j.eswa.2019.112900

Hewa, T., Braeken, A., Liyanage, M., & Ylianttila, M. (2022). Fog computing and blockchain-based security service architecture for 5G industrial IoT-enabled cloud manufacturing. *IEEE Transactions on Industrial Informatics*, *18*(10), 7174–7185. https://doi.org/10.1109/TII.2022.3140792

Hoque, M. A., & Hasan, R. (2019). Towards an analysis of the architecture, security, and privacy issues in vehicular fog computing. In *2019 SoutheastCon* (pp. 1–8). IEEE. https://doi.org/10.1109/SoutheastCon42311.2019.9020476

Hou, X., Li, Y., Chen, M., Di Wu, Jin, D., & Chen, S. (2016). Vehicular fog computing: A ciewpoint of cehicles as the infrastructures. *IEEE Transactions on Vehicular Technology*, *65*(6), 3860–3873. https://doi.org/10.1109/TVT.2016.2532863

Hu, P., Dhelim, S., Ning, H., & Qiu, T. (2017). Survey on fog computing: architecture, key technologies, applications and open issues. *Journal of Network & Computer Applications*, *98*, 27–42. https://doi.org/10.1016/j.jnca.2017.09.002

Huang, C., Lu, R., & Choo, K.-K. R. (2017). Vehicular fog computing: Architecture, use case, and security and forensic challenges. *IEEE Communications Magazine*, *55*(11), 105–111. https://doi.org/10.1109/MCOM.2017.1700322

Hussain, M. M., & Beg, M. M. S. (2019). Fog computing for Internet of Things (IoT)-aided smart grid architectures. *Big Data and Cognitive Computing*, *3*(1), Article 8. https://doi.org/10.3390/bdcc3010008

IEEE. (n.d.–a). *Conference Authors: Understand Peer Review*. Retrieved July 31, 2023, from https://conferences.ieeeauthorcenter.ieee.org/understand-peer-review/

IEEE. (n.d.–b). *Journal Authors: About the Peer Review Process*. Retrieved July 31, 2023, from https://journals.ieeeauthorcenter.ieee.org/submit-your-article-for-peer-review/about-the-peer-review-process/

IEEE Communications Society. (n.d.). *IEEE Communications Magazine*. Retrieved July 31, 2023, from https://www.comsoc.org/publications/magazines/ieee-communications-magazine

IEEE Communications Society. (2023). *IEEE Communications Magazine.* IEEE Communications Society. https://www.comsoc.org/publications/magazines/ieee-communications-magazine

Ilyas, A., Alatawi, M. N., Hamid, Y., Mahfooz, S., Zada, I., Gohar, N., & Shah, M. A [Mohd Asif] (2022). Software architecture for pervasive critical health monitoring system using fog computing. *Journal of Cloud Computing*, *11*, Article 84. https://doi.org/10.1186/s13677-022-00371-w

Iorga, M., Feldman, L., Barton, R., Martin, M. J., Goren, N., & Mahmoudi, C. (2018). Fog computing conceptual model: Recommendations of the National Institute of Standards and Technology. *Special Publication 500-325 (NIST SP)*, 1–8. https://doi.org/10.6028/NIST.SP.500-325

Jaiswal, R., Chakravorty, A., & Rong, C. (2020). Distributed fog computing architecture for real-time anomaly detection in smart meter data. In *2020 IEEE Sixth International Conference on Big Data Computing Service and Applications (BigDataService 2020) // 2020 IEEE Sixth International Conference on Big Data Computing Service and Applications: Proceedings* (pp. 1–8). IEEE. https://doi.org/10.1109/BigDataService49289.2020.00009

Jalowiczor, J., Rozhon, J., & Voznak, M. (2021). Study of the efficiency of fog computing in an optimized LoRaWAN cloud architecture. *Sensors*, *21*(9), Article 3159. https://doi.org/10.3390/s21093159

Ji, W., Liang, B., Wang, Y., Qiu, R., & Yang, Z. (2020). Crowd V-IoE: Visual Internet of Everything architecture in AI-driven fog computing. *IEEE Wireless Communications*, *27*(2), 51–57. https://doi.org/10.1109/MWC.001.1900349

Karagiannis, V., & Schulte, S. (2020). Comparison of alternative architectures in fog computing. In Y. Simmhan & B. Varghese (Eds.), *The 4th IEEE International Conference on Fog and Edge Computing: Proceedings* (pp. 19–28). IEEE. https://doi.org/10.1109/ICFEC50348.2020.00010

Khumalo, N., Oyerinde, O., & Mfupe, L. (2019). Fog computing architecture for 5G-compliant IoT applications in underserved communities. In *2019 IEEE 2nd Wireless Africa Conference (WAC): Proceedings* (pp. 1–5). IEEE. https://doi.org/10.1109/AFRICA.2019.8843414

Knebel, F. P., Wickboldt, J. A., & Freitas, E. P. de (2021). A cloud-fog computing architecture for real-time digital twins. *ArXiv*. Advance online publication. https://doi.org/10.48550/arXiv.2012.06118

Ksentini, A., Jebalia, M., & Tabbane, S. (2018). Survey on architectual and energetic aspects on fog computing environment. In *2018 IEEE 27th International Conference on Enabling Technologies: Infrastructure for Collaborative Enterprises (WETICE 2018): Proceedings* (pp. 30–35). IEEE. https://doi.org/10.1109/WETICE.2018.00013

Liu, Y., Fieldsend, J. E., & Min, G. (2017). A framework of fog computing: Architecture, challenges, and optimization. *IEEE Access*, *5*, 25445–25454. https://doi.org/10.1109/ACCESS.2017.2766923

Luo, Y., Chen, Y., & Wu, J [Junchao] (2021). Energy efficient fog computing with architecture of smart traffic lights system. In R. Alfred, H. Haviluddin, A. P. Wibawa, J. Santoso, F. Kurniawan, H. Junaedi, P. Purnawansyah, E. Setyati, H. T. T. Saurik, E. I. Setiawan, E. R. Setyaningsih, E. Pramana, Y. Kristian, K. Kelvin, D. D. Purwanto, E. Kardinata, & P. Anugrah (Eds.), *Proceedings: The 3rd East Indonesia Conference on Computer and Information Technology (EIConCIT) 2021* (pp. 248–254). IEEE. https://doi.org/10.1109/EIConCIT50028.2021.9431873

Maharjan, A. M. S., & Elchouemi, A. (2020). Smart parking utilizing iot embedding fog computing based on smart parking architecture. In *2020 5th International Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA 2020): Proceedings* (pp. 1–9). IEEE. https://doi.org/10.1109/CITISIA50690.2020.9371848

Maheswaran, M., Yang, T., & Memon, S. (2019). A fog computing framework for autonomous driving assist: Architecture, experiments, and challenges. In T. Pakfetrat, G.-V. Jourdan, K. Kontogiannis, & R. Enenkel (Eds.), *CASCON '19: Proceedings of the 29th Annual International Conference on Computer Science and Software Engineering* (pp. 24–33). IBM Corp. https://www.proquest.com/working-papers/fog-computing-framework-autonomous-driving-assist/docview/2262976519/se-2

Mai, T. D. (2019). Research on Internet of Things security architecture based on fog computing. *International Journal of Distributed Sensor Networks*, *15*(11), 1-10. https://doi.org/10.1177/1550147719888166

Malic, N. H. A., Izhar, T. A. T., & Kadir, M. R. A. (2020). Analysis review on the factors influencing fog computing adoption for organization. *International Journal of Scientific & Technology Research*, *9*(2). https://www.ijstr.org/paper-references.php?ref=IJSTR-0220-30786

Mayer, A. H., Rodrigues, V. F., Da Costa, C. A., Da Rosa Righi, R., Roehrs, A., & Antunes, R. S. (2021). FogChain: A fog computing architecture integrating blockchain and Internet of Things for personal health records. *IEEE Access*, *9*, 122723–122737. https://doi.org/10.1109/ACCESS.2021.3109822

Mekki, T., Jabri, I., Rachedi, A., & Ben Jemaa, M. (2018). Towards multi-access edge based vehicular fog computing architecture. In *2018 IEEE Global Communications Conference (GLOBECOM): Proceedings* (pp. 1–6). IEEE. https://doi.org/10.1109/GLOCOM.2018.8647850

Mell, P., & Grance, T. (2011). The NIST definition of cloud computing: Recommendations of the National Institute of Standards and Technology. *Special Publication 800-145 (NIST SP)*, 1–3. https://nvlpubs.nist.gov/nistpubs/legacy/sp/nistspecialpublication800-145.pdf

Mihai, V., Dragana, C., Stamatescu, G., Popescu, D., & Ichim, L. (2018). Wireless sensor network architecture based on fog computing. In *2018 5th International Conference on Control, Decision and Information Technologies (CoDIT)* (pp. 743–747). IEEE. https://doi.org/10.1109/CoDIT.2018.8394851

Mirzaie, S., AvazAghaei, M. R., & Bushehrian, O. (2021). Anomaly detection in urban water distribution grids using fog computing architecture. In *2021 29th Iranian Conference on Electronical Engineering (ICEE)* (pp. 591–595). IEEE. https://doi.org/10.1109/ICEE52715.2021.9544486

Muneeb, M., Ko, K.-M., & Park, Y.-H. (2021). A fog computing architecture with multi-layer for computing-intensive IoT applications. *Applied Sciences*, *11*(24), Article 11585. https://doi.org/10.3390/app112411585

Nadeem, S., Rizwan, M., Ahmad, F., & Jaweria Manzoor (2019). Securing cognitive radio vehicular ad hoc network with fog node based distributed blockchain cloud architecture. *International Journal of Advanced Computer Science and Applications*, *10*(1), 288–295. https://doi.org/10.14569/IJACSA.2019.0100138

Naha, R. K., Garg, S., Georgakopoulos, D., Jayaraman, P. P., Gao, L., Xiang, Y., & Ranjan, R. (2018). Fog computing: Survey of trends, architectures, requirements, and research directions. *IEEE Access*, *6*, 47980–48009. https://doi.org/10.1109/ACCESS.2018.2866491

Ning, Z., Huang, J., & Wang, X. (2019). Vehicular fog computing: Enabling real-time traffic management for smart cities. *IEEE Wireless Communications*, *26*(1), 87–93. https://doi.org/10.1109/MWC.2019.1700441

Nurnoby, M. F., & Helmy, T. (2023). A real-time deep learning-based smart surveillance using fog computing: A complete architecture. *Procedia Computer Science*, *218*, 1102–1111. https://doi.org/10.1016/j.procs.2023.01.089

Open Edge Computing Initiative. (2023). *About.* Open Edge Computing Initiative. https://www.openedgecomputing.org/about/

OpenFog Consortium Architecture Working Group. (2017). *OpenFog Reference Architecture for Fog Computing*. https://www.iiconsortium.org/pdf/OpenFog_Reference_Architecture_2_09_17.pdf

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., . . . Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ (Clinical Research Ed.)*, *372*, Article n71. https://doi.org/10.1136/bmj.n71

Patel, S., & Patel, R. (2022). Fog computing: A comprehensive analysis of simulation tools, applications and research challenges with use cases. *Journal of Engineering Science and Technology Review*, *15*(3), 63–83. https://doi.org/10.25103/jestr.153.08

Pecori, R. (2018). A virtual learning architecture enhanced by fog computing and big data streams. *Future Internet*, *10*(1), Article 4. https://doi.org/10.3390/fi10010004

Perera, C., Qin, Y., Estrella, J. C., Reiff-Marganiec, S., & Vasilakos, A. V. (2018). Fog computing for sustainable smart cities. *ACM Computing Surveys*, *50*(3), Article 32. https://doi.org/10.1145/3057266

Perifanis, N.-A., & Kitsios, F. (2022). Edge and fog computing Business value streams through IoT solutions: A literature review for strategic implementation. *Information*, *13*(9), Article 427. https://doi.org/10.3390/info13090427

Pompl, M. (2023, July 15). *Gefahr von Waldbränden in Südeuropa steigt.* ARD Athen, tagesschau. https://www.tagesschau.de/ausland/europa/hitze-suedeuropa-100.html

Priyadarshini, R., Barik, R. K., & Dubey, H. (2018). Deepfog: Fog computing-based deep neural architecture for prediction of stress types, diabetes and hypertension attacks. *Computation*, *6*(4), Article 62. https://doi.org/10.3390/computation6040062

Quy, V. K., van Hau, N., van Anh, D., & Le Ngoc, A. (2022). Smart healthcare IoT applications based on fog computing: Architecture, applications and challenges. *Complex & Intelligent Systems*, *8*(5), 3805–3815. https://doi.org/10.1007/s40747-021-00582-9

Raman, A. so (2019). Potentials of fog computing in higher education. *International Journal of Emerging Technologies in Learning*, *14*(18), 194–202. https://doi.org/10.3991/ijet.v14i18.10765

Rampérez, V., Soriano, J., & Lizcano, D. (2018). A multidomain standards-based fog computing architecture for smart cities. *Wireless Communications & Mobile Computing*, *2018*, Article 4019858. https://doi.org/10.1155/2018/4019858

Rani, M., Guleria, K., & Panda, S. N. (2021). Enhancing performance of cloud: Fog computing architecture, challenges and open issues. In *2021 9th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)* (pp. 1–7). IEEE. https://doi.org/10.1109/ICRITO51393.2021.9596498

Sabireen, H., & Neelanarayanan, V. (2021). A review on fog computing: Architecture, fog with iot, algorithms and research challenges. *ICT Express*, *7*(2), 162–176. https://doi.org/10.1016/j.icte.2021.05.004

Santos, J., Hooft, J. van der, Vega, M. T., Wauters, T., Volckaert, B., & Turck, F. De (2021). Srfog: A flexible architecture for virtual reality content delivery through fog computing and segment routing. In T. Ahmed (Ed.), *Proceedings of the IM 2021 - 2021 IFIP/IEEE International Symposium on Integrated Network Management* (pp. 1038–1043). IEEE.

Schmitz, F. (2022). *Der Klimawandel bedroht Griechenlands Olivenbäume.* Deutsche Welle. https://www.dw.com/de/der-klimawandel-bedroht-olivenb%C3%A4ume-in-griechenland/a-63560838

Silva, C. A., Aquino, G. S., Melo, S. R. M., & Egídio, D. J. B. (2019). A fog computing-based architecture for medical records management. *Wireless Communications & Mobile Computing*, *2019*, Article 1968960. https://doi.org/10.1155/2019/1968960

Singh, S., Chiu, Y.-C., Tsai, Y.-H., & Yang, J.-S. (2016). Mobile edge fog computing in 5G era: Architecture and implementation. In *2016 International Computer Symposium (ICS 2016): Proceedings* (pp. 731–735). IEEE. https://doi.org/10.1109/ICS.2016.0151

Singh, S. P., Nayyar, A., Kumar, R., & Sharma, A. (2019). Fog computing: From architecture to edge computing and big data processing. *Journal of Supercomputing*, *75*(4), 2070–2105. https://doi.org/10.1007/s11227-018-2701-2

Soua, A., & Tohme, S. (2018). Multi-level SDN with vehicles as fog computing infrastructures: A new integrated architecture for 5G-VANETs. In *2018 ICIN Conference and Workshops* (pp. 1–8). IEEE. https://doi.org/10.1109/ICIN.2018.8401604

SpringerOpen. (n.d.). *Journal of Internet Services and Applications: About*. Retrieved July 31, 2023, from https://jisajournal.springeropen.com/about

Steve Bogart. (n.d.). *SankeyMATIC Manual*. Retrieved July 22, 2023, from https://sankeymatic.com/manual/

Subedi, B., & Sharma, G. (2022). A state-of-the-art review on fog computing architecture, applications, and security issues. *International Journal of Advanced Networking and Applications*, *13*(6), 5188–5196. https://www.proquest.com/scholarly-journals/state-art-review-on-fog-computing-architecture/docview/2695515007/se-2

Tahmasebi, S., Habibi, J., & Shamsaie, A. (2020). A scalable architecture for monitoring IoT devices using ethereum and fog computing. In *2020 4th International Conference on Smart City, Internet of Things and Applications (SCIOT 2020)* (pp. 66–76). IEEE. https://doi.org/10.1109/SCIOT50840.2020.9250193

Tsipis, A., Papamichail, A., Koufoudakis, G., Tsoumanis, G., Polykalas, S. E., & Oikonomou, K. (2020). Latency-adjustable cloud/fog computing architecture for time-sensitive environmental monitoring in olive groves. *AgriEngineering*, *2*(1), 175–205. https://doi.org/10.3390/agriengineering2010011

Vailshery, L. S. (2022). *Number of IoT connected devices worldwide 2019-2021, with forecasts to 2030*. https://www.statista.com/statistics/1183457/iot-connected-devices-worldwide/

Varshney, P., & Simmhan, Y. (2017). Demystifying fog computing: Characterizing architectures, applications and abstractions. In *Ieee 1st International Conference on Fog and Edge Computing (ICFEC 2017): Proceedings.* IEEE. https://doi.org/10.1109/ICFEC.2017.20

Vega, F. de la, Soriano, J., Jimenez, M., Lizcano, D., & Raquel Lacuesta (2018). A peer-to-peer architecture for distributed data monetization in fog computing scenarios. *Wireless Communications & Mobile Computing, 2018,* Article 5758741. https://doi.org/10.1155/2018/5758741

Vieru, C. (2018). *AWS IoT-Driven Precision Agriculture.* Amazon Web Services Inc. The Internet of Things on AWS – Official Blog. https://aws.amazon.com/de/blogs/iot/aws-iot-driven-precision-agriculture/?pg=ln&sec=c

Volkoff, O., & Strong, D. M. (2018). Affordance theory and how to use it in IS research. In R. D. Galliers & M.-K. Stein (Eds.), *Routledge companions in business, management and accounting. The Routledge companion to management information systems* (pp. 232–245). Routledge. https://doi.org/10.4324/9781315619361-18

Wadhwa, H., & Aron, R. (2018). Fog computing with the integration of Internet of Things: Architecture, applications and future directions. In J. Chen & L. T. Yang (Eds.), *2018 IEEE Intl Conf on Parallel & Distributed Processing with Applications, Ubiquitous Computing & Communications, Big Data & Cloud Computing, Social Computing & Networking, Sustainable Computing & Communications (ISPA/IUCC/BDCloud/SocialCom/SustainCom): Proceedings* (pp. 987–994). IEEE. https://doi.org/10.1109/BDCloud.2018.00144

Wang, H [Haoxin], Liu, T., Kim, B., Chung-Wei, L., Shiraishi, S., Xie, J., & Zhu, H. (2020). Architectural design alternatives based on cloud/edge/fog computing for connected vehicles. *IEEE Communications Surveys & Tutorials*, *22*(4), 2349–2377. https://doi.org/10.1109/COMST.2020.3020854

Wang, H [Huifen], Wang, J., & Tang, Q. (2018). A review of application of affordance theory in information systems. *Journal of Service Science and Management*, *11*(1), 56–70. https://doi.org/10.4236/jssm.2018.111006

Wang, P., Lin, W.-H., Wu, B.-H., Chao, K.-M., & Lo, C.-C. (2018). A cross-age face recognition approach using fog computing architecture for user authentication on mobile devices. In *Proceedings: 2018 IEEE 15th International Conference on e-Business Engineering (ICEBE 2018)* (pp. 86–93). IEEE. https://doi.org/10.1109/ICEBE.2018.00023

Webster, J., & Watson, R. T. (2002). Analyzing the past to prepare for the future: Writing a literature review. *MIS Quarterly*, *26*(2), xiii–xxiii. http://www.jstor.org/stable/4132319

Wei, X., & Wu, L. (2019). A new proposed sensor cloud architecture based on fog computing for Internet of Things. In *2019 IEEE International Congress on Cybermatics: 12th IEEE International Conference on Cyber, Physical and Social Computing, 15th IEEE International Conference on Green Computing and Communications, 12th IEEE International Conference on Internet of Things, 5th IEEE International Conference on Smart Data (CPSCom/GreenCom/iThings/SmartData 2019): Proceedings* (pp. 615–620). IEEE. https://doi.org/10.1109/iThings/GreenCom/CPSCom/SmartData.2019.00120

Yassein, M. B., Hmeidi, I., Shatnawi, F., & Rawasheh, S. (2020). Fog computing: Characteristics, challenges and issues. In *2nd International Conference on Mathematics and Computers in Science and Engineering (MACISE 2020): Proceedings* (pp. 240–245). IEEE. https://doi.org/10.1109/MACISE49704.2020.00051

Yousefpour, A., Fung, C., Nguyen, T., Kadiyala, K., Jalali, F., Niakanlahiji, A., Kong, J., & Jue, J. P. (2019). All one needs to know about fog computing and related edge computing paradigms: A complete survey. *Journal of Systems Architecture*, *98*, 289–330. https://doi.org/10.1016/j.sysarc.2019.02.009

Zhang, H., Qin, B., Tu, T., Guo, Z., Gao, F., & Wen, Q. (2020). An adaptive encryption-as-a-service architecture based on fog computing for real-time substation communications. *IEEE Transactions on Industrial Informatics*, *16*(1), 658–668. https://doi.org/10.1109/TII.2019.2948113

Zhang, W [Wenyu], Zhang, Z., & Chao, H.-C. (2017). Cooperative fog computing for dealing with big data in the Internet of Vehicles: Architecture and hierarchical resource management. *IEEE Communications Magazine*, *55*(12), 60–67. https://doi.org/10.1109/MCOM.2017.1700208

Zheng, W., Wang, W., Wu, G., Xue, C., & Wei, Y. (2020). Fog computing enabled smart grid blockchain architecture and performance optimization with DRL approach. In J. Wu (Ed.), *2020 IEEE 8th International Conference on Computer Science and Network Technology (ICCSNT 2020)* (pp. 41–45). IEEE. https://doi.org/10.1109/ICCSNT50940.2020.9305000

Zhu, C., Zhang, W [Wenjun], Chiang, Y.-H., Ye, N., Du, L., & An, J. (2022). Software-defined maritime fog computing: Architecture, advantages, and feasibility. *IEEE Network*, *36*(2), 26–33. https://doi.org/10.1109/MNET.003.2100433

Zhu, J., Chan, D. S., Prabhu, M. S., Natarajan, P., Hu, H., & Bonomi, F. (2013). Improving web sites performance using edge servers in fog computing architecture. In J. E. Guerrero (Ed.), *Proceedings: 2013 IEEE Seventh International Symposium on Service-Oriented System Engineering* (pp. 320–323). IEEE. https://doi.org/10.1109/SOSE.2013.73

Zhu, X., Chan, D. S., Hu, H., Prabhu, M. S., Ganesan, E., & Bonomi, F. (2015). Improving video performance with edge servers in the fog computing architecture. *Intel Technology Journal*, *19*(1), 202–224. http://www.redi-bw.de/db/ebsco.php/search.ebscohost.com/login.aspx%3fdirect%3dtrue%26db%3dbuh%26AN%3d110788653%26site%3dehost-live

Declaration about the Thesis

Ich versichere wahrheitsgemäß, die Arbeit selbstständig verfasst, alle benutzten Quellen und Hilfsmittel vollständig und genau angegeben und alles kenntlich gemacht zu haben, was aus Arbeiten anderer unverändert oder mit Abänderungen entnommen wurde, sowie die Satzung des KIT zur Sicherung guter wissenschaftlicher Praxis in der jeweils geltenden Fassung beachtet zu haben.

Karlsruhe, den 31. Juli 2023 YANNICK ERB