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DYNAMICS OF DEPLOYING EDGE COMPUTING IN SOUTH AFRICAN HIGHER EDUCATION INSTITUTIONS

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ABSTRACT

The purpose of this study was to conceptualize an edge computing deployment framework for the South African Universities context. The study argues that South African Higher Education Institutions (HEI) systems can improve by introducing technologies such as fog and edge computing to connect the smart devices that are shaping the present and future. This was to improve efficiency in day-to-day HEI operations and to gain a competitive advantage. To assist in understanding the adoption of edge computing, Unified Theory of Acceptance and Use of Technology (UTAUT), Task-Technology-Fit (TTF) and Media Research Theory (MRT) theories were used as research lenses. Other relevant tools and technologies for deployment, such as Wi-Fi, smart devices, and big data storage, are derived from data collected. The model is envisaged to improve the adoption, deployment and use of edge computing in university settings.

Keywords: *Edge Computing, Higher Education Institutions, UTAUT, TTF and MRT.*

1. INTRODUCTION

Student enrolment has seen increases since the establishment of the "Fees Must Fall" student movement and protests in South Africa by [1] Universities are facing the challenge of increasing their IT resources to accommodate this exponential rise in the student population, the use of ICT has become a major requirement. The growing popularity of associated smart appliances around the world is shaping the future of the modern world [2].

According to [3] cloud and edge computing are two software paradigms that cannot replace each other because they are equally important. Cloud and edge computing offer end-user data, processing, storage, and application services. However, according to [4] Compared to cloud computing, edge computing varies based on its closeness to consumers, spread across different locations, and provision of mobility assistance.

Edge computing refers to a distributed computing approach in which computing tasks are mainly or entirely carried out on decentralized edge devices, termed as edge computing nodes, instead of predominantly within a centralized cloud setting [5]. Recently, numerous novel solutions have emerged to tackle the everyday challenges associated with creating more intelligent platforms. Edge computing stands out as a promising technology capable of tackling these challenges. This study argues that considering an integrated edge-cloud architecture will reduce resource costs and delays to serve real-time applications at a lower operating cost.

1.1 Problem Statement

The following observations further support the fact that there is still some knowledge gap in the realization of the value of advanced computing at South Africa's University of Technology.

- The Intellectual capital gap in fog computing is revealed, which has not been addressed sufficiently. The following observations also support some knowledge gaps in the realization of the value of advanced computer technology in a unit.
- Insufficient literature on the adoption or use of advanced computer technology by South African higher education institutions.
- It lacks theoretical and practical models to demonstrate the value of edge computing.
- Security issues in edge computing environments still pose some concerns.
- The common industries that use fog computers are manufacturing, transportation, communication, health, and agriculture. In South Africa's higher education institutions, cutting-edge computers are required.

  Since the current literature does not mention this phenomenon, there is no

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"knowledge" or "knowledge" about the use of advanced computing in higher education institutions. Technology innovations in South Africa.

This study sets out to determine how edge computing deployment could be conceptualized at higher education institutions. The introduction of edge computing is known for reducing network or service latency, benefiting from near the devices and reduced network/service response time [6]. The study therefore examines the advantages and challenges of advanced computing in higher education institutions.

1.2 Research Objectives

The primary goal of this research was to conceptualize the dynamics of edge computing deployment in South African higher education institutions. The secondary research objectives were:

1. To explore edge computing and its deployment, understanding and experience by ICT staff in South African higher education institutions
2. To investigate the deployment models and frameworks that exist for edge computing at higher education institutions.
3. To explore the Acceptance and Use themes for edge computing at higher education institutions.
4. To explore the Task–Technology-Fit benefits and challenges of edge computing at higher education institutions.
5. To investigate technology richness themes that are relevant for edge computing at higher education institutions.

1.3 Research Questions

The primary research question of the study was "What are the dynamics of deploying edge computing in South African higher education institutions?

The research sub-questions (RSQ) are formulated thus:

1. What is your understanding and experience of edge computing at your institution?
2. Which deployment models and frameworks exist for edge computing at higher education institutions?
3. What is the acceptance and use themes for edge computing at higher education institutions?
4. How can technology such as edge computing be adopted and used to overcome some of the challenges facing South African higher education institutions on the ICT environment?
5. What are the technology richness themes that are relevant for edge computing at higher education institutions?

2. LITERATURE REVIEW

Higher education's edge computing is influenced by three key factors: networking capacity, technological integration, and improved learning environments. First, edge computing enables sharing and processing of educational data closer to the source, minimizing latency problems. Secondly, traditional network technologies, such as IoT and cloud computing, are used to enable real-time access to resources. Thirdly, it is in line with modern teaching approaches, improving digital interactions and creating more immersive learning experiences.

HEIs increasingly adopt cutting-edge computers to support flexible learning environments. The need for real-time data processing and the reduction in dependence on centralized cloud servers have pushed universities to explore edge-based solutions [7]. Research suggests that HEI recognizes the need for a continuous educational model that allows students to access learning materials at anytime and anywhere, thereby reducing the limitations of traditional classroom environments [8].

The role of IoT in education is particularly important. It has been shown that incorporating IoT in HEI improves the management of digital resources, improves autonomous control, and ensures greater reliability of infrastructure [9] Research shows that edge computing guided by IoT can facilitate a seamless access to digital content, increasing student engagement and reducing technical bottlenecks [10].

2.1 Concept Models and Theoretical Frameworks

Several theoretical frameworks have been used to assess the adoption of HEI technology. UTAUT is widely used to explain the behavioral factors that influence the adoption of new technologies. However, existing technology adoption models have

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some limitations in predicting institutions' readiness to fully integrate edge computing.

2.1.1 Performance expectations and adoption of edge computing.

Performance Expectancy (PE) is the perceived benefit of using technologies to improve academic and administrative processes. Studies have shown that PE is strongly linked to the adoption of edge computing because it improves data efficiency, reduces latency, and optimizes learning experience. The study [11] confirmed that PE is the main factor that influences university adoption of mobile and advanced computing technologies.

2.1.2 Social influence and adoption of edge computing.

Social influence (SI) plays a key role in the acceptance of new technologies, particularly in education institutions, where teachers, students, and administrative staff influence the behaviors adopted [12]. [13] found that peer recommendations and institutional policies have a significant impact on the adoption of technology in HEIs. SI is especially relevant in advanced computing, where its widespread acceptance depends on the institution's culture and the support of IT departments.

2.1.3 Effort Expectancy and Edge Computing Usability

Effort Expectancy (EE) refers to the ease of use and perceived effort required to integrate new technologies [14]. Research shows that when faculty and students can use technology easily, HEIs will adopt advanced computing more likely. In addition, EE has a direct impact on the likelihood of long-term adoption and use patterns in academic institutions.

2.1.4 Facilitating Conditions and Technological Readiness

Facilitation conditions (FCs) relate to infrastructure, technical support, and institutional policies that enable the adoption of new technologies [15]. Studies have shown that organizations with strong IT management and investments in digital infrastructure are more likely to successfully implement edge computing [16]. Furthermore, FC is an important determinant of the institution's ability to scale edge computing initiatives across multiple campuses.

2.2 Computing paradigm evolution and issues

The evolution of computing paradigms is characterized by the development of significant technological advances and the emergence of new methods to meet the growing demand for data processing and management. Figure 1 supports the different paradigms [18]. Transition from traditional computing models to modern models such as cloud, edge, and fog computing reflects the limitations of previous systems, especially in terms of scalability, latency, and resource management.

Different levels of computing load, mobility management, traffic load technology, cache acceleration, network control, etc. are among the basic components of edge computing [17].

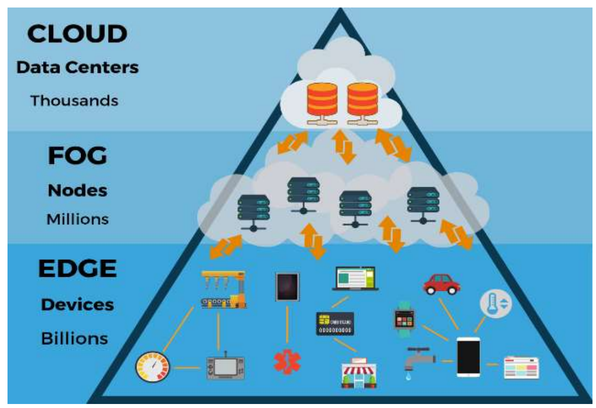

Figure 1: Cloud, Fog, and Edge computing paradigms [18]

The history of edge computing [19] is outlined on Figure 2 starting with content delivery in the 1900s.

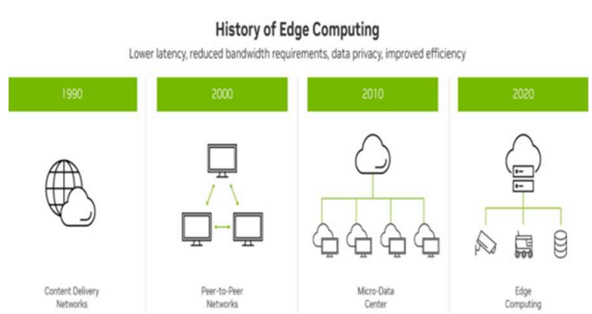

Figure 2: History of Edge Computing [19]

2.3 Benefits of Edge Computing

There are various advantages of deploying edge computing discovered by [20] below:

- Speed-edge computing accelerates data streams, including real-time data processing without latency. Therefore, intelligent applications and devices can react almost immediately to data generated [21].

- Effective and safe - Edge computing enables efficient processing of vast amounts of data near its origin. This approach reduces bandwidth usage and costs while helping to optimize application efficiency from remote locations. The processing of data without it being placed in the public cloud provides an additional layer of security for organizations managing sensitive data [22].

- Scalability and versatility - Edge computing is a cheaper alternative to specialized data centres and can be incorporated into IoT devices and edge data centres to enhance the computing capabilities of organizations. In addition, the addition of additional devices does not significantly increase the demand for network bandwidth, so edge computing devices with processing capacity can also contribute to reducing the cost of growing.

- Powerful data storage- The edge devices receive data from the cloud, which has vast processing power and storage capacity [23]

- Reliability: edge computing is more reliable since data is processed near the end-user, making it resistant to security threats and network failures.

2.4 Challenges of Edge Computing

Higher education institutions must recognize the challenges associated with edge computing. The following problem arises with edge computing [20]

- Power supply: edge devices are power-restricted devices with a limited power source. The edge must be able to process without interruption at any moment. This necessitates skilled power utilization by the edge devices for the system to operate well [24]

- Deployment: space and a physical environment are both lacking in edge devices. It must be customized to the context of the application. The processing skills required at the edge must be constrained by the available space.

- Maintenance: Because of the decentralized architecture, the system requires regular maintenance to work correctly. To avoid disruptions in system services, device failures must be addressed in advance [25]

- Backup: edge computing collects and analyses data from various sources. For service providers to comprehend all gathered data, a complete data protection strategy is essential. Reliable data storage and access are required to improve application security.

3. RESEARCH AND DESIGN METHODOLOGY

According to [26], Research methods are described as "the general approach adopted by researchers in focus on research processes and research methods.

There are three types of research methods: qualitative, quantitative, and mixed methods. Research was conducted using a qualitative research methodology, because the research method chosen provided the university with a deep and real perspective through semi-structured interviews [27].

3.1 Research Philosophy

Research philosophy is the first layer of research onion. According to [28] Research philosophy refers to the belief system and assumptions about knowledge development, conducting research projects. Research methods, Research philosophy is chosen based on the assumptions of the researcher's view and perception of the world. Research philosophy can be considered positive theory, critical realism, interpretation theory, postmodern theory, and pragmatism [29].

Interpretation philosophy is chosen because research philosophy allows people to seek their views, opinions, perceptions, and experiences about the use of advanced computing. Interpretivism is used because it is a new field that is not well known and is not well understood.

3.2 Research Approach

There are three types of research methods commonly used in information systems research: qualitative, quantitative, and mixed methods. Research will be conducted using a qualitative research methodology, because the research method chosen will provide the university with a deep and real perspective through semi-structured interviews [28].

3.3 Data Collection Methods

This study was conducted using semi-structured interviews and document inspection. The interview guide is used as a research tool to collect key data on participants' experience and knowledge of edge and cloud computing. As a result of the Covid-19 epidemic, researchers collected data from online platforms such as Microsoft Teams and Zoom, including face-to-face interviews.

Data collection processes included invitations to participants followed by scheduling interviews. Confirmations were given at the beginning of the interview. The information collected during the interview remains confidential. The data was securely stored at the university according to the ethics committee requirements. Document inspections were recorded, and track documents related to the study using document analysis guides.

3.4 Data Analysis

The study used thematic analysis [30] as indicated on Table 1. Semi-structured interview audios were transcribed into plain text. The text transcribed were analysed into codes, code categories then the development of themes. Codes were also generated from research objectives.

Table 1: Phases of thematic analysis adopted [30].

Phase	Description of the process
1. Familiarizing yourself with your data	Transcribing data, reading and re-reading the data.
2. Generating initial codes	Coding interesting features of the data across the entire data set.
3. Searching for themes	Collating of codes into potential themes, gathering all data relevant to each potential.
4. Reviewing themes	Checking if the themes work with the coded extracts.
5. Defining and naming themes	An ongoing analysis will be conducted to refine the specifics of each theme.
6. Producing the report	The final opportunity for analysis. Selection of vivid, compelling extract examples and final analysis of selected extracts.

4. DATA ANALYSIS AND RESULTS

Data analysis is performed using thematic analysis (TA). Thematic analysis is an instrument used to define, analyse and report data patterns. The six stages of thematic analysis by [30] They were employed. Six stages include data knowledge, code generation, code fusion, theme review, theme description, and result report.

In the first phase, the recorded data was translated into Microsoft Word for thematic analysis. In this process, a more comprehensive understanding of the data was developed. In Step 2, the data is used to generate the initial code. In the third phase, the theme map is created by linking the entire dataset's code to the theme map. The fourth stage included the development and change of similar themes. The fifth stage included the creation of the final theme map. The sixth phase consists of synthesizing the results of the data and writing a report using a comprehensive set of developed themes.

4.1 Research Setting

The research interviews occurred on different campuses across the TUT environment. It occurred in all the TUT campuses, including distance campuses, main and CBD campuses. All the campuses have their own administrative offices. The TUT campuses as indicated below:

- The main TUT campus is based in Pretoria West.
- The CBD Tshwane university is Arts, Arcadia, Alma, and Du Toit, Breytenbach Theatre, Building and Estates, Metro Skinner, and Business School.
- The research also participated at the Distance campuses, which are eMalahleni, Mbombela, and Polokwane campuses.

4.2 Data Analysis Process

I. The interview data was captured and uploaded on Atlas Ti as documents.

II. Next the data was read multiple times as part of the familiarization stage.

III. A hybrid coding approach was followed, featuring both deductive and inductive coding.

IV. The theoretical constructions were loaded as deductive (a priori) codes.

V. Inductive coding resumed with initial and line by line from the interview data collected.

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VI. The coding method used In Vivo Coding uses participants' own words to create a coding scheme for analysis.

VII. Memos were also created for interview questions, theoretical lens, and researcher's journal on RSQ.

VIII. Categories were developed based on patterns. The themes were formulated from the categories.

4.3 Participants Roles and Responsibility

The interviewees included Data centre managers, IT technical staff, Security experts, project managers, and line managers as indicated on Table 2. The core areas of focus were ICT decision-making and the primary activities.

To ensure anonymity, the researchers allocated pseudonyms to each participant, such as Participant_01, Participant_02, and Participant_03, to preserve their confidentiality. This may be related to their role within the ICT department.

4.4 Participant's Decision-making and Primary Tasks

The interviewees included data centre managers, IT technical staff, security experts, project managers, and line managers. The core areas of focus were ICT decision-making and the primary activities. To ensure anonymity, the researcher allocated pseudonyms to each participant, such as Participant_01, Participant_02, and Participant_03, to preserve their confidentiality. This may be related to their role within the ICT department.

Table 2: Participants' demographic profile.

Participant ID	Participant Role	Years of experience	Years of experience with cloud or edge	Interview duration (minutes)
01	Network Admin	8	4	40
02	Network Engineer	9	6	38
03	Hosting & Database Manager	11	5	28
04	Network Engineer	7	3	35
05	Security Admin	12	6	45
06	Network Engineer	12	5	20
07	Network Admin	12	3	35
08	Desktop Support Engineer	13	4	30
09	Database & Hosting Engineer	12	5	25
10	Deputy Director project management	9	3	40
	Totals	104	44	336 min
	Averages	10.4%	4.4%	33.6 min

4.5 Findings from Interviews

The study objective was to explore edge computing and its deployment understanding and experience by ICT staff in South Africa.

The following conclusions are drawn from literature and empirical evidence.

- Most participants were aware of the advantages of edge computing and their application in South African higher education.
- Based on participants' responses, deployments seem to be interchangeable with implementations.
- Edge Computing allows for the distribution. And allows for these devices and applications, and these cloud services to be processed locally to be closer to the source.

Findings on study objective: *To investigate the deployment models and frameworks that exist for edge computing at higher education institutions:*

- The findings revealed that most of the participants show a fair understanding of edge computing and how they are deployed.
- Their understanding of edge computing is the key to successful deployments in the South African higher education.

The study objective: To explore the Acceptance and Use themes for edge computing at higher education institutions.

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- From the participant's responses, it seems that deployments cannot be used interchangeably with the implementation.

- Edge computing allows for distribution. And allows for these devices and applications, and these cloud services to be processed locally to be closer to the source.

Findings on study objective: *To explore the Task–Technology-Fit benefits and challenges of edge computing at higher education institutions*:

- Results indicate that the user-required process must be followed and considered.

Edge computing is becoming more and more accepted in different kinds of organizations.

Findings for study objective: *To investigate technology richness themes that are relevant for edge computing at higher education institutions*:

- The research explains that edge computing can support research initiatives. Edge computing can also be used to support the various applications and perform its optimal levels.

- Edge computing improves security and efficiency and reduces network costs.

Additional findings that contributed to themes:

_Participant role and responsibility in computing and ***_TTF of edge computing*** has the highest groundedness meaning most participants well presented their roles and responsibilities. They also shared the task technology fit of edge computing.

_Participant shared or referred documentation or online sources; few participants shared their documentation, hence the low grounded ness. ***_The security concern*** was a challenge for a few participants.

_Deployment understanding and experience, _Task-Technology- Fit-Other challenges of edge computing together with ***_Technology richness themes for edge computing*** have a medium or neutral grounded ness. Participants were not clear enough about the challenges of edge computing.

4.6 Themes and conceptualization of the dynamics of deploying edge computing

The themes below were developed from the category codes that are identified through the study objectives. The sub themes were analysed from the participants' responses on the interview guide.

The theoretical framework could support the adoption and use of technologies and may serve as the basis for research on the use of clouds, edge devices, and cloud computing. Various frameworks have been employed to comprehend the progression of cloud computing within university settings.

Table 3: Themes and Sub-themes derived from data

Themes	Sub-Themes
1. Participant role and responsibility in computing	-Network support engineer. To design, implement, and maintain any organization's network infrastructure
2. Other relevant tools and technologies for deployment	-Big data stored in the data centre. -Wi-fi for network connectivity. -Use of smart devices to communicate.
3. Participant in education, training, and experience in computing	-Capacity issues. -Competencies like your skill sets and training. -The need for training on new technologies
4. Deployment models and frameworks that exist.	-To follow the user requirements process. -Process of analysis, pilot implementation, and roll out to larger communities. -ICT security policies onboard.
5. Decision making and security concern	-Develop a budget and timeline, and present the proposal to the management, and wait for approval. -Security risks such as data breaches, unauthorized access, and cyber-attacks.

Figure 3 below represents the conceptualized model supported by Table 3:

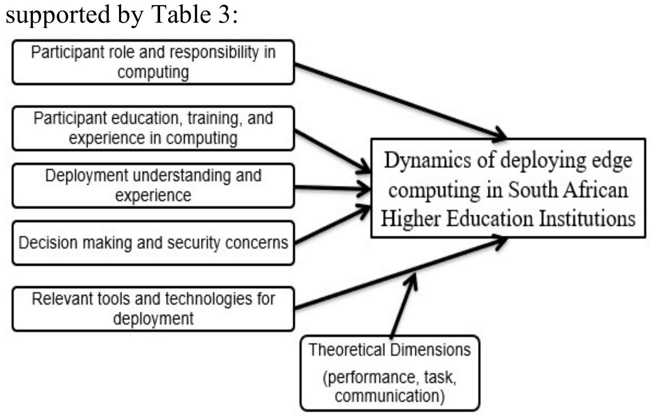

Figure 3: Conceptual model for dynamics of edge computing in SA HEs

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5. SUMMARY, RECOMMENDATIONS, AND CONCLUSION

5.1 Study Contributions

Dynamics of deploying edge computing in South African higher education institutions:

- South African universities would be better equipped to introduce advanced computing technologies to connect future-oriented smart devices, improve efficiency in daily operations, and gain competitive advantage through edge computing.
- A model was conceptualized addressing dynamics of deploying edge computing in South African higher education institutions.
- The practical contribution will be the use of model by future generations of cloud computing in South African universities.
- The deployment of edge computing will improve the use of edge computing in South African higher education institution settings.

5.1.1 Theoretical Contributions

Theories of UTAUT, TTF and MRT were applied as research lenses through which to conceptualize the development dynamics of deploying edge computing in higher education institutions in South Africa. This contribution demonstrated how the three theories can assist in determining how to implement edge computing in higher education institutions.

5.1.2 Practical Contributions

The proposed model may be practically applied towards improving the use of cutting-edge computing in the context of South African higher education institutions.

5.2 Study Limitations

Due to time and cost constraints, this study focused on the dynamics of implementing advanced computing in South African higher education institutions. The study is confined to the higher education sector in South Africa. The study was conducted in the higher education sector, and the results and recommendations can be applied to other sectors, such as the government and the private sector.

The limitation of time also led to studies conducted at a given time rather than longitudinal studies over a long period. Another limitation is the sampling method, with the inclusion criteria of TUT staff who know and have work experience or use edge computing.

5.3 Future Research and Recommendation

This study provides suggestions for future research:

- Future studies may be conducted in developing countries to compare current research with other emerging technologies.
- Other theoretical frameworks can be used to expand the use of advanced computing technologies in the higher education sector.
- Longitudinal study designs can present additional dynamics to improve the proposed model.

The study was aimed at determining how edge computing deployments in higher education institutions were conceptualized.

The research problem that the present study aimed to solve was that the knowledge gap in edge computing had not yet been sufficiently addressed. In addition, it was supported by the absence of limited literature on the adoption or use of advanced computing in higher education institutions in South Africa. There is a lack of theoretical and practical models to demonstrate the value of edge computing. In edge computing environments, some problems, such as security problems, must be addressed. Although the current literature on this phenomenon is still silent, there is still a lack of "knowledge" about using modern computers in higher education institutions.

5.4 Summary of Findings

The goal of this study was to determine how edge computing deployment can be conceptualized at higher education institutions.

5.4.1 Summary of the study objectives

This goal was achieved through the following objectives:

- To study the understanding and experience of the development of edge computing and its deployment by ICT staff in higher education institutions in South Africa.
- To investigate the deployment models and frameworks that exist for edge computing at higher education institutions.
- To explore the Acceptance and Use of themes for edge computing at higher education institutions.
- To explore the Task-Technology-Fit benefits and challenges of edge computing at higher education institutions.

- To investigate technology richness themes that are relevant for edge computing at higher education institutions.

6. CONCLUSION

The study conceptualized an advanced deployment model for South African universities using UTAUT, TTF and MRT as research lenses. This contributed to a gap in theoretical knowledge. Introduction of edge computing will improve the use of edge computing in South Africa's higher education institutions. The study further contributed to the evolution of next-generation cloud computing for South African universities.

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