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Preface

This SAICSIT 2023 proceedings contains a selection of the revised accepted research papers of SAICSIT 2023, the 44th Conference of the South African Institute of Computer Scientists and Information Technologists. SAICSIT 2023 was held from 17 to 19 July 2023 at the 26 Degrees South Bush Boho Hotel in Muldersdrift, South Africa. The theme of the conference is Connect to be the Future.

The power of face-to-face time has been proven repeatedly, and for any community to flourish, all members must flourish. The past few years have demonstrated our connectedness as the Covid-19 pandemic spread worldwide. On the plus side, our interconnectedness supports innovation and creativity, leading, in many cases, to more success for individuals and organisations. The strength of weak ties is a well-known social network concept. We all benefit from accessing new and non-redundant information through those ad-hoc connections we usually do not see in everyday interactions. Unfortunately, large groups are becoming less interconnected in our world of remote interaction, and we should aim to address these challenges as Computing scholars. The role of the 44th SAICSIT conference is to connect the computing community so that innovation and creativity can flourish. The SAICSIT conference aims to provide a space to meet and exchange ideas on addressing the challenges of the fast-evolving digital future.

This SAICSIT 2023 proceeding contains 12 full research papers organised in their respective Computer Science and Information Systems research tracks. These submissions are included for presentation in the program of SAICSIT 2023. 58 papers were submitted, and 54 submissions in total were

sent out for review. Of these, 18 papers were selected for publication in the Springer CCIS volume 1878, giving an acceptance rate of 31%. A further 12 papers were included in this online proceedings, giving a total acceptance rate of 52%. More than 75% of the contributions in this online proceedings came from different universities.

The double-blind review process was rigorous, with every paper receiving at least three substantive reviews from an expert program committee with more than 20 national and international affiliations. The track chairs managed the review process and supported the authors in revising their papers to the quality results that are published in this proceedings. We want to express our gratitude to the track chairs and program committee reviewers for their hard work and dedication. Thank you to the submitted papers' authors for sharing their research results. We hope the opportunity to participate in SAICSIT 2023 will impact the quality and productivity of future research in our scholarly community.

We also acknowledge the enthusiasm and outstanding contributions of the local organisers of SAICSIT 2023, the School of Computer Science and Information Systems at the North-West University in South Africa. The administration, faculty, and staff of the North-West University, as well as our conference organiser, Mongoose C&D, supported the planning and execution of the conference.

Thank you to everyone who contributed to the success of SAICSIT 2023.

October 2023
Aurona Gerber and Marijke Coetzee
Publication Co-chairs: SAICSIT 2023

Our Sponsors

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Authentication and Privacy by Zero-Knowledge Protocols

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Abstract. Zero-knowledge protocols are distributed algorithms that allow a sender to convey knowledge of some secret to a receiver without actually communicating the secret itself. These protocols are important in authentication and privacy, as they enable secure asynchronous communication without the need for trusted third parties. The concept of zero-knowledge may seem paradoxical, but it simply refers to the fact that no additional information beyond the truth of the statement is revealed. In this paper we use epistemic logic to formalise authentication, privacy and zero-knowledge in terms of "who knows what" and reason about their attainment using a canonical zero-knowledge protocol as benchmark. By using epistemic logic with a modal operator K for knowledge, we can express statements like "agent A knows that φ" and reason about the implications of these statements for a distributed sender and receiver. Finally, the work analyzes Lamport's One-Time Password Authentication Scheme as a zero-knowledge protocol that achieves authentication and privacy. Zero-knowledge protocols are a powerful tool for achieving authentication and privacy, and their formalisation using epistemic logic provides a rigorous framework for reasoning about security. The practical example with Lamport's scheme helps to demonstrate the robustness of definitions for authentication and privacy.

Keywords: Authentication, Epistemic Logic, Privacy, Zero-Knowledge.

1 Introduction

An increasing number of physical objects like sensors, household appliances, and security cameras now connect to the internet forming what is called the Internet of Things (IoT) networks. Connecting these objects not only creates new exciting ways to share information but also creates new avenues for attack. A particularly extreme attack, called the Mirai botnet, used close to 300,000 IoT devices to cause a massive distributed denial of service on critical server systems [4]. Thus a major challenge with IoT networks is to ensure that devices are safe from unauthorized access and data breaches.

Zero-knowledge protocols offer a robust method for preventing unauthorized access by leveraging authentication processes. In an authentication scenario, these protocols enable a sender to demonstrate knowledge about their identity to a receiver without revealing sensitive information through a communication channel. This ensures that sensitive identity information remains confidential while still providing convincing evidence of authenticity to the receiver.

Moreover, zero-knowledge protocols play a crucial role in privacy-preservation schemes, where the focus is on safeguarding personally identifiable information. By employing these protocols, organizations can conceal sensitive data while still allowing authorized entities to perform necessary operations without compromising individual privacy. By harnessing the capabilities of zero-knowledge protocols, security measures can be strengthened, user privacy can be protected, and the risk of unauthorized access can be minimized effectively.

Zero-knowledge protocols were introduced by Goldwasser, Micali and Rackoff [16] as a way of proving the truth of statement using a mathematical formula without actually giving a proof. In such a setting, a prover is able to convince a verifier of the truth of a statement without revealing any additional information. In this instance, the prover wants to show it knows some secret. The verifier challenges the prover over several rounds by asking questions, to which the prover must respond correctly with overwhelming probability. The protocol is able to withstand attacks with high probability. For example, if the prover does not know the secret and wants to falsely authenticate itself, then it is infeasible for the prover to pretend it knows the secret over many communication rounds. It is also infeasible for a verifier to work out what the secret is by challenging the prover over many rounds.

The term “zero knowledge” seems paradoxical due to the fact that at least one bit of information is revealed regarding the truth of a statement. However, the term simply refers to the fact that the verifier, even a dishonest one, learns nothing new that it did not know before the start of the proof. Together with cryptography techniques, zero-knowledge protocols achieve user authentication while safeguarding sensitive information from potential attackers.

In this paper, we study how authentication and privacy are achieved by zero-knowledge protocols. To do that we first express authentication and privacy as invariant knowledge predicates in a distributed system with message passing as a form of communication. Knowledge predicates tell us what agents know about a property and also allow us to express knowledge about knowledge. In order to reason about knowledge, we use epistemic logic, which formalises notions of knowledge and belief. Epistemic logic allows us to express statements like “agent A knows that φ” using a modal operator K for knowledge. We also use it to reason about the implications of these statements based on a sound and complete semantics by Kripke [18]. In order to gain confidence in our definitions of authentication and privacy, we apply the definitions to a benchmark case study following a canonical zero-knowledge protocol [13, 14].

Finally, we give an example of Lamport’s One-Time Password Authentication Scheme and show that it achieves authentication and privacy. This scheme uses a shared secret key and a hash function to generate a one-time password that is sent to

the verifier. The verifier can check the validity of the password without learning any information about the secret key beyond its validity. Thus we also show that the scheme achieves zero-knowledge of the secret key value. Lastly, we show that Lamport's scheme can be implemented on IoT devices with limited computational power, making it a secure and practical authentication method for IoT devices.

The rest of the paper is organised as follows. Section 2 provides background on zero-knowledge protocols and discusses some of its applications. Section 3 describes the message passing and security models required for our setting, as well as the logic and mathematical structures needed to reason about authentication and privacy. Section 4 gives definitions of authentication and privacy. Section 5 formalises a real-world scheme as zero-knowledge protocol and shows that it attains authentication and privacy. Finally, Section 6 concludes with a summary and remarks.

2 Background

Goldwasser et al. [16] introduced zero-knowledge protocols in the context of distributed prover and verifier. These protocols enable constant interaction between the parties to prove the validity of a statement. The proofs solve complex computational problems such as the discrete logarithm or quadratic non-residue problems. However, deploying these protocols in IoT environments presents unique challenges due to limited resources, such as bandwidth and battery life.

To address the limitations of constant interaction, Blum and Feldman [7] introduced non-interactive proof systems. These systems utilize a common reference string that allows the prover and verifier to derive necessary information without further interaction. This approach is particularly useful in scenarios where continuous interaction is expensive, such as resource-constrained IoT networks. Non-interactive proof systems provide an efficient way to authenticate IoT devices without the need for constant online connectivity.

Both interactive and non-interactive zero-knowledge proofs share essential properties [13]: completeness, soundness, and zero-knowledge. Completeness ensures that a valid prover can convince the verifier of the proof's correctness with overwhelming probability. Soundness guarantees that a dishonest prover cannot convince the verifier with more than a negligible probability. Zero-knowledge ensures that the verifier gains no additional information beyond the proof's validity. Any deviation from these properties would be considered a security flaw.

Various instantiations of zero-knowledge protocols exist, such as the Schnorr identity scheme [23] and the Diffie-Hellman key distribution protocol [10], which prove knowledge of a discrete logarithm. The Fiat-Shamir authentication scheme [14] and the Guillou-Quisquater protocol [17], which demonstrate knowledge of a modular root. These protocols have been thoroughly analyzed, verified, and successfully implemented in real-world applications.

For instance, Maurya et al. [22] analyzed the Fiat-Shamir authentication scheme using a symbolic model checker tool and identified flaws. Brandt et al. [8] implemented the scheme on a 32-bit chip, and were able to successfully verify a 512-bit

key in 0.7 seconds. Furthermore, zero-knowledge protocols have found applications in preserving privacy for blockchain technologies. They conceal payment transaction information in cryptocurrencies like Bitcoin and Ethereum [6, 2, 1].

However, it is essential to address the challenge of understanding what exactly is meant by zero-knowledge and its implications for authentication and privacy. To provide clarity, this work aims to offer an explicit definition of authentication, privacy, and the zero-knowledge property as was introduced by Goldwasser et al. [16] and later strengthened by Blum and Feldman [7]. Departing from complexity analysis, this research introduces a level of abstraction using epistemic logic, enabling a clearer understanding of the claims made by protocols regarding authentication and privacy. To this end, Section 3 presents the building blocks for defining and reasoning about authentication and privacy.

3 Preliminaries

This section presents the message passing framework, security model and mathematical objects needed to reason about authentication and privacy by zero-knowledge protocols.

3.1 Message passing

We consider distributed systems in which agents have disjoint state space and interact by message passing (rather than by sharing state) [20]. Each agent can perform an input, output, or an internal computation on its state space. State spaces are disjoint, and message passing is asynchronous but uncorrupted.

The notation $A \rightarrow B : x$ means that agent A (the origin), sends value x to agent B (the destination), which asynchronously receives it. At this level of abstraction liveness is assumed.

3.2 Security model

We have arbitrary many agents with no quantum capabilities that exchange messages. We also have adversaries that eavesdrop on connections and remember all communications, know the algorithms being used between agents, but whose computations are bounded by polynomial-time. This model is commonly referred to as the Dolev-Yao model [11].

3.3 Epistemic logic

'Who knows what' is expressed and reasoned about using epistemic logic which extends predicate logic with a (modal) operator for 'agent A knows that ϕ' written $K_A\, \varphi$ [12]. We consider the dual operator for K_A to be $\neg K_A \neg \varphi$, which reads "it is possible agent A knows that φ". Semantics of K_A is given by an accessibility relation between an agent's possible worlds, reflecting its state of knowledge [12].

The following laws for the knowledge operator are sound with respect to that semantics:
1. Only truths are known: $\vdash K_A \varphi$ then $\vdash \varphi$;
2. Knowledge is conjunctive:
$\vdash (K_A \varphi \wedge K_A \psi)$ then $\vdash K_A (\varphi \wedge \psi)$;
3. Infinite regress is avoided by 'introspection':
$\vdash (K_A \varphi)$ then $\vdash K_A (K_A \varphi)$
$\vdash (\neg K_A \varphi)$ then $\vdash K_A (\neg K_A \varphi)$;
4. Knowledge is gained or lost by communication (according to Chandy and Misra [9]):

$A \rightarrow B : \varphi$
$B \rightarrow A : ack(\varphi)$,

when B receives φ then KB φ then it knows φ, that is, $\vdash K_B \varphi$. When B acknowledges φ using the function $ack(\cdot)$, it can be seen as achieving "I know you have received a value", without which that information is unattainable. Conversely, if at some stage of communication $\vdash \neg K_A \varphi$ and at a later stage $\vdash K_A \varphi$ then between those two stages A received a message.

3.4 Infeasibility

The notion of infeasibility is essential for reasoning about the capabilities of an intruder. A computation is infeasible if it takes exponential time, over non-trivial sized inputs, in the standard (i.e., not a quantum) model. For instance, if one has a security key one would ideally pick one of sufficient size that would be difficult to guess. A non-trivial size key might be 256-bits longs accompanied with no better algorithm than trying 2256 possible solutions to compute it. This is incomputable in our lifetime in the standard model.

3.5 Hash function

Hash functions are invaluable in the task of creating infeasible computations.

Definition 1. *A cryptographic hash function $h : \mathbb{B}^* \rightarrow \mathbb{B}^m$ maps a bit-string of arbitrary length to a random bit-string of length m. It satisfies, amongst others, these properties:*

1. h is deterministic (as distinct from probabilistic, for example) and quick to compute (polynomial time);

2. h is one-way, so inverting h is infeasible: the range of h in $\mathbb{B}^m$ is sufficiently large that given an element y it is infeasible to find x such that $h(x) = y$. Moreover even though some positive iteration of h equals the identity, its period is infeasible and so more generally given $i > 0$ it is infeasible to find x such that $h^i(x) = y$;

3. h is collision-free, in particular, although the range may be smaller than the domain in which case h is not injective, given x it is infeasible to find $z \neq x$

such that h(z) = h(x).

In Section 4, we use the building blocks in the previous section to provide explicit definitions of privacy, authentication and zero-knowledge. We then reason about the attainment of these properties using a canonical zero-knowledge protocol as a benchmark.

4 Security Properties

Here we define privacy, authentication, and zero-knowledge epistemically. An initiator *A* initiates a connection with a responder *B* and they establish a shared secret φ when each knows φ:

$$Shared(A,B,\varphi) := K_A\,\varphi \wedge K_B\,\varphi \tag{1}$$

Definition 2 (Privacy). *When agents who share a secret are the only ones who know it, we say the secret is private:*

$$Private(A,B,\varphi) := Shared(A,B,\varphi) \wedge (\forall C \neq A, B \cdot \neg K_C\,\varphi) \tag{2}$$

When each agent also knows the other knows ϕ, we say ϕ is endorsed between them:

$$Endorsed(A,B,\varphi) := K_A\,\varphi\,K_B\,\varphi \wedge K_B\,\varphi K_A\,\varphi \tag{3}$$

Definition 3. *When a secret is endorsed, each agent is assured the other knows φ rather than an intruder, and we say a connection is authenticated:*

$$Authenticated(A,B,\varphi) := Endorsed(A,B,\varphi) \wedge (\forall C \neq A, B \cdot \neg K_C\,\varphi) \tag{4}$$

Authentication ensures that two agents know they are conversing with each other and to no one else.

Definition 4. *In a non-interactive protocol, a verifier B has zero knowledge of the value of φ when prover A knows that φ but B does not know that φ, and B knows that A knows that φ:*

$$ZK(A,B,\varphi) := K_A\,\varphi \wedge \neg K_B\,\varphi \wedge K_B\,\varphi K_A\,\varphi \tag{5}$$

The example in Figure 1 shows how the Diffie-Hellman key distribution protocol achieves zero-knowledge ZK (Equation (5)) of a randomly selected secret value ɑ. The example uses the computational Diffie-Hellman hardness problem to prove knowledge of discrete logarithms.

Definition 5. *The computational Diffie-Hellman (CDH) problem in a multiplicative group G of order q generated by g is to find* $\varphi = g^{\alpha\beta}$ *given* g^{α} *and* g^{β} *, when* α *and* β *have been chosen independently and uniformly at random from {0, 1, 2, . . . , q − 1}.*

Definition 6. *The discrete logarithm problem (DLP) in a multiplicative group G is to find the discrete logarithm x to the base g, when x has been chosen uniformly at random from the group.*

In the example, a prover A chooses a random secret value $\alpha :\in \mathbb{Z}_q$, and computes a common random string φ, which it shares with verifier B. So now A and B share a common string φ, that is, $K_A\ \varphi$ and $K_B\ \varphi$.

Then A generates a random commitment $w = g^{\beta}$ were β is chosen uniformly at random from $\mathbb{Z}_q$. At the same time, it generates a challenge c using a hash function h with the properties in Definition 1. And it computes a response s. Agent A sends to B its commitment and response s.

Upon receiving the pair (w, s), B computes c' and checks whether $g^s = \varphi w^{c'}$. If B is convinced, it accepts the proof and concludes that it knows that A knows that α, $K_B K_A \alpha$. If B is not convinced, it rejects the proof, and concludes that it is possible that A knows α, $\neg K_A \neg\alpha$.

$$
\begin{array}{lll}
A: \alpha :\in \mathbb{Z}_q; & & \\
\quad \phi = g^{\alpha} (\bmod\ q) & & K_A\ (\alpha \wedge \phi) \\
 & & \\
A \rightarrow B: \phi & & K_B\ \phi \text{ and } \neg K_B\ \alpha \\
 & & \\
A: \beta :\in \mathbb{Z}_q; & & \\
\quad \omega = g^{\beta} (\bmod\ q); & & \\
\quad c = h(\phi, \omega); & & \\
\quad s = c\alpha + \beta & & \\
 & & \\
A \rightarrow B: (\omega, s) & & \\
 & & \\
B: c' = h(\phi, \omega) & & \\
\quad \text{if} \quad g^s = \omega \phi^{c'} & \text{then } B \rightarrow A: Accept & K_B K_A \alpha \\
 & \text{else } B \rightarrow A: Reject & K_B(\neg K_A \neg\alpha)
\end{array}
$$

Fig. 1. A canonical protocol. Prover A at first inputs α, computes g^{α}, a challenge c and response s. The verifier B inputs (w, s), computes the same challenge c' and determines whether the proof is zero-knowledge, that is, *ZK* (Equation (5)) holds.

In the case of a cheating verifier, B will rewind the protocol and receive another $g^{s'}$. Now the verifier has two challenges and can work out α given $g^s = \varphi w^{c1}$ and $g^{s'} = \varphi w^{c2}$. Assuming $c1 - c2 \neq 0$,

$$g^s / g^{s'} = \varphi w^{c1} / \varphi w^{c2} = g^{a} w^{c1} / g^{a} w^{c2} \Rightarrow g^{s-s'} = g^{a(c1-c2)} \Rightarrow \alpha = (\text{s - s'})/(c1 - c2)$$

Under the CDH assumption, it is computationally infeasible for a cheating verifier to search a for group $\mathbb{Z}_q$ with large order.

In Section 5, we will use the same reasoning to conduct a thorough analysis of Lamport's One-Time Password Authentication Scheme. Normally, Lamport's scheme is considered a commit-reveal scheme whereby a prover chooses a secret value and later reveals it to the verifier [15]. However, we treat Lamport's scheme as a zero-knowledge protocol and show that it achieves zero-knowledge of some secret key value.

5 Lamport's One-time Password-Authentication Scheme

Repeated access to a critical region of a computer system requires each access to be authenticated and certain information hidden from intruders. A user might for example, identify itself to the system without revealing their password because in the event that an intruder intercepts this password, it may start to impersonate the user. An authentication scheme is required that protects sensitive user information.

Lamport's One-Time Password-Authentication Scheme, [19] L_AOTP, lets a user encode its password and then generate a sequence of one-time passwords from that. The next one-time password is obtained by applying a one-way hash function h to the previous one-time password. The way the sequence is generated can be simple or complex. But the approach prevents intruders from working out the next one-time password simply because inverting h is infeasible. L_AOTP sets the i-th password in the sequence to equal $h^{n-i}(a)$, where a is the password and hn denotes n iterations of h. It suffices for the user to store a and for it to simply compute $h^{n-i}(a)$ when an access request is made to the system. This eliminates the need to compute the sequence of one-time passwords offline before using them.

Indeed, in order to obtain the next one-time password in the sequence, an intruder has to invert h, for example, an intruder that knows h^{n-2} , to compute the next password, it must compute: $h^{-1}(h^{n-2}(a)) = h^{n-3}(a)$. This computation is infeasible even for an intruder with perfect memory that knows the hash function.

Authentication happens when a system validates the one-time passwords by comparing the generated one-time password with the one it is storing. If the hashed values match, the system updates its current store with the next one-time password. Similar to the user, it suffices for the system to store just one previous one-time password and not the sequence, and update it when authentication succeeds. By hiding the password and making computation of h^{-1} infeasible, L_AOTP achieves authentication.

Indeed Lamport's One-Time Password Authentication scheme is still relevant today. One-Time Passwords are used two-factor authentication [3] for transactions like online banking, in push notifications to a user's mobile phone, and in emails sent to authenticate a login.

This section provides a treatment of L_AOTP in two parts: its functional correctness, and then its efficiency within the bounds required for its use by the Internet of Things (IoT).

5.1 How L_AOTP works

Assume distributed agents *A* and *B*. *A*'s state consists of an arbitrarily large natural number *n* which equals the number of accesses it will perform, a secret value *a*, and counter for the current one-time password *i.* It is assumed that *A* and *B* share the hash function *h*. *A* computes a current hashed target *x*, and then sends to B the value $y := h(x)$, which *B* stores. See the Init procedure in Figure 2.

B's state includes a database mapping each user to its hashed target. However for simplicity we consider only one user, *A*. After its initial access, *A* asks *B* for access by presenting *x*. *A* increments $i := i + 1$ and computes the next hashed target $x := h^{n-(i+1)}(a)$. *A* reinitialises when *i* reaches *n*. B authenticates by applying *h* to *x* to check the result equals its stored target value: $h(x) = y$. *B* then updates the target $y := x$. When the update succeeds, *B* sends to *A* an *Accept* message; otherwise it sends a *Reject* message. Thus each time *A* wants to access *B*, it presents *B* with the current hashed target *x*, increments $i := i + 1$ and computes the next hashed target. *B* then checks *x* against the value y stored in its database and updates it. See the recursive procedure X in Figure 2. The hashed target x is used only once; any attempt to reuse it results in authentication failure. Hence the name *one-time password*.

Proposition 1. *L_AOTP achieves zero-knowledge of a secret value chosen by an honest prover.*

Proof. Let *a* be the secret value chosen by prover *A*. The *X*-iteration of the design in Figure 2 terminates because the non-negative variant function *i* increments on each iteration. Moreover it maintains the invariant

$A : 1 \leq i < n \wedge x = h^{n-i}$ *(a)*

$B : y = h(x)$.

It remains to strengthen the invariant to include property *ZK(A, B, a)*. Consider an arbitrary iteration.

Firstly $K_B\, K_A\, x$ since $A \rightarrow B : x$.

Secondly, according Law 4, $K_A\, K_B\, x$ since *B* accepts the proof and sends to *A* an acknowledge which *A* receives.

Thirdly, according to Property 2 in Definition 1, even if $K_B\, x$ it is computationally infeasible for B to compute and know, that is, $\neg\, K_B$ a. □

Proposition 2. *Assume that A, B are honest and follow the protocol. Then L_AOTP achieves Authenticated (Equation (4)).*

Proof. The *X*-iteration of the design in Figure 2 maintains the invariant *Authenticated* (Equation.(4)) in the following way.
When *B* checks that $h(x) = y$ and updates $y := x$, it is knows that *A* knows that *x* is the latest update, $K_B\, K_A\, x$. When *B* sends to *A* the accept message, according to Law (4), $K_A\, K_B\, x$.
Finally an intruder *E* knows all values of *x* from previous iterations. But for *E* to compute the next hashed target is equivalent to it computing h^{-1} , which is infeasible according to Property 2 in Definition 1). So by the assumption on *E*, $\neg K_E\, x$. □

Proposition 3. *Assume that A, B are honest and follow the protocol. Then L_AOTP achieves Private (Equation (2)).*

Proof. By Law (1) *Endorsed* in *Authenticated* implies *Shared*.
Finally, it is computationally infeasible for an intruder *E* to compute the latest values of *x* given previous values of *x*. So by the assumption on *E*, $\neg K_E\, x$. □

$$
\begin{array}{lll}
Init := & A : n :\in \mathbb{N} \mid n \geq 2\,; & \\
 & \quad a :\in \mathbb{Z}_q\,; & \\
 & \quad i := 1\,; & \\
 & \quad x := h^{n-i}(a)\,; & \\
 & \quad y := h(x)\,; & \\
 & A \to B : y; & \\
 & & \\
X := & A : \textbf{if } i < n \textbf{ then } A \to B : x & \\
 & \qquad\qquad\qquad\quad i := i + 1\,; & \\
 & \qquad\qquad\qquad\quad x := h^{n-i}(a) & \\
 & \qquad\qquad\quad \textbf{else } \ Init & \\
 & B : \textbf{if } h(x) = y \textbf{ then } y := x\,; & \\
 & \qquad\qquad\qquad\qquad\quad B \to A : \ Accept\,; & \\
 & \qquad\qquad\qquad\qquad\quad X & \\
 & \qquad\qquad\qquad\quad \textbf{else } \ B \to A : \ Reject &
\end{array}
$$

Fig. 2. The LAOTP Protocol, *Init;X* , between *A* and *B*, in which *A* reinitialises after *n* accesses, using hash function *h*, which is common to *A* and *B*. Initialisation of both *A* and *B* involves *A* setting parameters and sending y to *B* for it to initialise its state.

Theorem 1. *Assume that A, B are honest and follow the protocol. Then L_AOTP is secure under the CDH assumption.*

Proof. By assumption that the hash function h has the properties in Definition 1 and its definition uses the *CDH* assumption (Definition 5), it remains to show that the secret value chosen by *A* is zero-knowledge *ZK (Equation (5))* in the protocol, and

that the protocol achieves *Authenticated (Equation (4))* and *Private (Equation (2))* in the presence of a malicious agent.
According to Proposition 1, the secret value a chosen by A is zero-knowledge in L_AOTP. According to Proposition 2, L_AOTP authenticates the latest x endorsed by A and B. Finally, in Proposition 3, the value endorsed by A and B is private between them. □

5.2 Complexity

The cost of computation for L_AOTP will be quantified in terms of space, time and number of communications. Time complexity of the protocol is the unit cost of operations performed by A and B. A computes a new one-time password x using hash function h while B checks that $h(x) = y$ and then updates its database with $y := h(x)$. The unit cost of computing a new one-time password is proportional to the function's input size. For instance, if h is based on the discrete logarithm problem, in the best-case, computing x in a group $\mathbb{Z}$ of order q requires running time $2^{O(q1/3 \log q2/3)}$ [21], which dominates time complexity.

Space complexity depends what size values need to be stored by participants. Agent A needs to securely store values $n, a, i,$ while B needs to store y associated with A. Since values are chosen from a group of order q, space required is $O(q)$ to within a constant multiple for the number of values that need to be stored.

Communication cost between A and B involves 3 message exchanges. In one iteration of L_AOTP, A and B exchange at most 3 messages – first where A shares a common random string $y,$ and then sends a new one-time password x to B, and finally when B sends either an accept or reject of x.

L_AOTP is fitting for devices with limited space and bandwidth. It is possible to fit L_AOTP onto IoT devices depending on the order q of group from which security values are selected. The National Institute of Standards and Technology (NIST) recommends a security strength, that is, a number associated with the amount of work of to break a security protocol, of 112-bits or greater [5]. Setting $q \geq 112$ is good in terms of time and space requirements for devices with constraints.

IoT devices working in remote settings with limited bandwidth can communicate securely with fewer messages. However, devices need to be sensitive to computational costs associated with complex hashing implementations that could drain IoT battery power. Therefore, networks must consider a secure and efficient hashing implementation to generate one-time passwords.

6 Conclusion

Zero-knowledge protocols are a powerful tool for achieving user authentication while safeguarding sensitive information from potential attackers. Through the use of epistemic logic, we have defined authentication, privacy, and zero-knowledge as invariant knowledge properties. Epistemic logic enables us to not only express knowledge about these properties but also knowledge about knowledge itself. By reasoning about

the attainment of these properties using a canonical non-interactive zero-knowledge protocol as a benchmark, we have demonstrated the effectiveness of our definitions.

To further validate the robustness of these definitions, we have conducted a thorough analysis of Lamport's One-Time Password-Authentication Scheme as a zero-knowledge protocol. Our analysis has confirmed that this protocol indeed achieves the desired property of zero-knowledge. By relying on a hardness assumption, we have shown that Lamport's scheme is secure and ensures that no additional information is disclosed beyond what is necessary for authentication. This effectively safeguards sensitive information from potential attackers. Furthermore, we have discovered that this protocol is well-suited for implementation on devices with limited bandwidth due to its minimal number of interactions between participants. This efficiency makes it practical for deployment in resource-constrained environments.

One notable advantage of our approach is the avoidance of complicated mathematical computations and probabilistic interpretations when expressing authentication and privacy. By focusing on what agents know, we can reason algebraically about their knowledge after the protocol execution. This perspective provides valuable insights into the knowledge state of the agents involved, facilitating a deeper understanding of the protocol's effectiveness.

In terms of future work, we propose utilizing our approach to examine privacy-enhancing technologies for multi-party interactions. Expanding our methodology to address complex scenarios involving multiple participants holds great potential for advancing privacy protection in such settings. By leveraging our framework, we can analyze and evaluate the efficacy of various privacy-enhancing technologies in these contexts.

In conclusion, our work demonstrates the power of epistemic logic in defining and reasoning about authentication, privacy, and zero-knowledge properties in cryptographic protocols. Through the analysis of Lamport's One-Time Password-Authentication Scheme, we have validated the effectiveness of our definitions. By adopting an approach that focuses on agents' knowledge and avoids complex computations, we gain valuable insights into the protocol's effectiveness and its suitability for practical implementation. Furthermore, our framework provides a solid foundation for future research into privacy-enhancing technologies for multi-party interactions.

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The Case for a Cray on a Chip

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Abstract. Moore's Law is usually interpreted as a prediction of how many transistors you can buy for the same money at some future date. It can also be interpreted as how long you need to wait until a given number of transistors falls below a target price. An example of this reverse-application of Moore's Law is transitions such as the emergence of microprocessors competitive with traditional larger-scale computers and the emergence of smartphones. Since the late 1990s, it has become increasingly common for growth in transistors to equate to more CPUs (cores) per die. Recent designs have over 50 billion transistors and far more potential parallelism than can be supported by memory. I argue the case for a rebalancing of design goals with a much larger, faster on-chip memory and a CPU that is designed around this memory system. The proposal: a Cray-class vector CPU on a die with 1 Gibyte of static RAM, or Crayon (for Cray on a chip). The kind of organization classically used by Cray vector supercomputers is feasible to achieve on a single chip. I argue that a design like this can use the available memory bandwidth, as opposed to over-CPU designs with a large number of cores and GPU threads that are memory limited and propose how such a design could be used.

Keywords: supercomputer vector architecture Moore's Law.

1 Introduction

The purpose of this paper is to predict a new technology inflection point, based on the same logic that could have been used to predict timing of when single-chip microprocessors would challenge the dominance of the mainframe and when it became feasible to build a smartphone at an affordable price. The specific prediction is that a vector CPU along the lines of an early Cray design, with a substantial on-chip static RAM memory, will soon be possible. Making the prediction presages more detailed studies to explore the design space.

Why is such a development a good idea? Memory access is a significant bottleneck in existing designs, so a design study reversing the trend of cramming more and more CPU power onto a chip is worth considering. Instead, the amount of CPU should be balanced with a significant-sized fast on-chip memory.

This paper makes the case for such a design alternative, while leaving open details, which can only be established with a full design study including simulations.

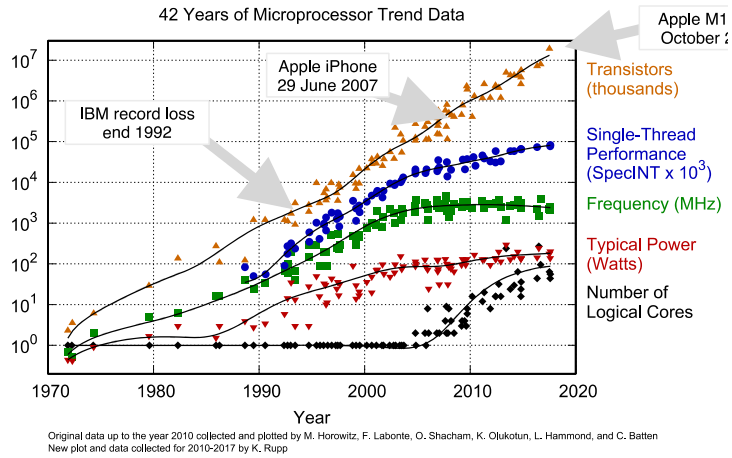


Fig. 2. Moore's Law trend showing major inflection points. When IBM made their record loss, RISC designs such as MIPS R4000 were appearing and Intel's Pentium was about to launch. The iPhone required a good enough ARM CPU. Apple M1 Max has 57-billion transistors.

Such a design study will need suitable workloads and to consider variations such as the ratio of transistors used for RAM versus logic and implementation of a high-speed network to scale up to large-scale systems.

Fig. 1 shows the general Moore's Law trend [15], with a few major inflection points added. In 1992, IBM had the then biggest loss in US corporate history [23]. That coincided with the rise of the "killer micro": cheap microprocessors that could supplant the high-performance computing market for mainframes at a fraction of the price. Only a few years later, specialist supercomputer makers started filing for bankruptcy [37]. The second inflection point is mid-2007, when it was possible to buy enough hardware to run a Unix-class kernel and still have enough resources for a decent application layer, making smartphones possible (some preceded the iPhone, but the iPhone launch marks the turning point where smartphones started to become ubiquitous). The third inflection point is late 2021, when processors with more than 50 billion transistors on a die started to appear.

What is the significance of these inflection points?

The classic view of Moore's Law is that it predicts how much more you can buy for the same money as a function of elapsed time, typically twice the transistors every eighteen months; repeated claims of the demise of this trend are another constant [44]. The transistor count trend line illustrated by the graphed examples hints at that. This is a useful metric, as it predicts how long a current purchase will last before it becomes obsolete. It also predicts how expensive a purchase is worth making now if you cannot use all its performance or expansion capacity immediately. If you spend down now, you may be able to do better next year.

The inflection points hint at another trend line: instead of a constant-price line, a constant-functionality line predicts when a certain level of functionality will fall

Table 1. Terminology.

Term		Definition
Ki	kibi-	binary prefix for $2^{10} = 1024$
Mi	mebi-	binary prefix for $2^{20} = 1024^2$
Gi	gibi-	binary prefix for $2^{30} = 1024^3$
Ti	tebi-	binary prefix for $2^{40} = 1024^4$
die		chip (as seen by hardware designers)
core		CPU or GPU on a die; if more than one
DRAM		dynamic random access memory
		each bit is a capacitor and must be refreshed
SRAM		static random access memory
		each bit is made of transistors and is not refreshed
ROM		read-only memory
bank		separately accessible unit of memory
ISA	instruction-set architecture	programmer-visible instructions and registers
microcode		low level instructions used to implement ISA
control store		ROM used to store microcode
μ-ops	micro-operations	simplified instructions generated in hardware
cache		fast SRAM memory close to CPU
		fastest is L1, nearest CPU, then L2, etc.
issue		instruction moves to execute pipeline stage
multi-issue		more than one instruction can execute at once
scalar		CPU that executes one instruction at a time
superscalar		CPU with a multi-issue pipeline

through a price point of interest. A killer micro became possible when a single-chip microprocessor with full functionality (integer, floating point and memory manager) could be made. A smartphone became possible when enough transistors could be bought, within the budget for a phone CPU, to run a good kernel and nontrivial graphical applications.

Gordon Bell predicts new classes of computer should emerge every 10 years [4] based on a similar analysis – though his categories differ as he does not consider devices like smartphones.

In Table 1, I summarize terminology to aid the non-specialist. Though I prefer using binary prefixes for memory sizes as those accurately reflect the hardware, if I cite a source that uses decimal prefixes like M and G (e.g., in Section 2), I use their terms, even if they may be inaccurate.

Having reached this point: should we not be looking for a new inflection point, based on delivering something previously impossible, now that over 50-billion transistors can be put on a die? In the remainder of this paper, I review the limitations of cramming CPU power onto a die, touch on trends in addition to Moore's Law and look for historical designs that could better use so many transistors. I select one and outline why it is a good idea, and where it takes us next. I end with conclusions.

2 Limits of Over-CPU Designs

It is useful to backtrack a bit to how we got to the current situation, where processor-heavy designs increasingly dominate the industry. In 1996, Kunle Olukutan made the case for a single-chip multiprocessor, now commonly referred to as multicore, based on the observation that aggressive multi-issue pipelines have diminishing returns. 4 CPUs able to issue two instructions per clock need about the same chip space as a single CPU able to issue 6 instructions per clock. Despite 3 times the peak throughput, the more aggressive design at best is 30% faster than the simpler design on a single thread or process and 4 simpler CPUs do better on multithreaded or multitasking workloads [30].

At the time Olukutan was making the case for a single-chip multiprocessor, one of the more aggressive designs available, the AMD-L6, had 88-million transistors and could issue 6 instructions – either real instructions, or micro-operations (μ-ops)[1] derived from real instructions – in one clock cycle [16]. Apple's M1 Max with 57-billion transistors has nearly 650 times as many. What are all these extra transistors used for? Some details have been made public [27] though Apple does not disclose as much as some. M1 Max has 10 regular CPUs, 32 GPUs and 16 NPUs (neural processing units, claimed to be capable of 11 trillion operations per second – though it is not clear if this is in the aggregate or per NPU). To make this all work without being totally memory-limited, Apple packages DRAM tightly with the CPU in a System in a Package (SiP) design. The 512-bit memory bus has four 16-bit 128-bit LPDDR5 channels. Cores are split into performance and efficiency; the former share a 12 MByte L2 cache and the latter a 4 MB L2 cache. Performance cores each have 192 KB of instruction and 128KB of data cache, and efficiency cores respectively 128 KB and 64 KB. With 8 performance and 2 efficiency cores, this adds up to nearly 3 MB of level 1 cache, for a total over all cores and levels of nearly 20 MB of cache.

Not taking into account the cache-control logic, with 6 transistors per bit (the usual SRAM implementation [45] though other variations are possible), this amount of cache requires about 950-million transistors, or less than 2% of the total of 57-billion transistors.

A design with as much CPU on one die as Apple's M1 Max is memory-constrained. Though Apple sells its designs with tightly-integrated DRAM, satisfying demand for so much processing is challenging. If all 58 processing units (10 CPUs,

[1] As a way of bridging the gap between complex instruction sets and RISC, some designers use μ-ops that break programmer-visible instructions into simpler operations; μ-ops are designed to be easier to pipeline than complex instructions [20].

32 GPUs, 16 NPUs) try to access DRAM at once, that becomes a major bottleneck. Even with a high bandwidth bus, contention is likely to be an issue particularly as all units are unlikely to be in lockstep and accessing the same region of memory. It would be interesting to know how many memory transactions are required to be interleaved with 11-trillion (1.1×10^{13}) NPU operations per second to sustain that rate with real-world computations. To add to that, for the conventional CPUs, though the L1 caches are a decent size, the L2 caches are not particularly large.

During the original supercomputer era, it was well known that there could be a very big gap between peak and achievable throughput, as revealed by an attempt at standardising application-level benchmarks [10]. Having a massive theoretical peak throughput that is not achievable has to be weighed against other uses of hardware resources that could be effectively utilised.

When the amount of computing power on a die is out of balance with reasonably achievable memory resources, I call this an "over-CPU" design.

A major drawback of Apple's approach to countering an over-CPU design by tightly integrating DRAM into the package is that it removes the option of memory upgrades. For a consumer computer, this is problematic as a buyer on a limited budget can stretch the usability of a machine by buying more DRAM, particularly as DRAM prices drop. Worse, it is not a sustainable strategy for future designs as the latency gain of this sort of packaging can only happen once; if the long-term trend of a growing speed gap between CPU and DRAM persists, an over-CPU strategy will see diminishing returns.

The Apple M1 Max exemplifies the problem; it is not the only example. Recent NVIDIA GPU designs have 80-billion transistors, with 50 Mbytes of cache [13], accounting for about 3% of the total transistors.

3 Trends and Learning Curves

There is a long history of changes in optimum instruction set architecture (ISA) being driven by memory technology. The ISA in broad terms is the programmer-visible instruction set, including instructions and registers. In very early systems with small memories, designs that led to compact code were optimal [12]. When a fast read-only memory (ROM) became an option, a *control store* containing *microcode* – code in a very low-level form that interpreted the ISA layer – became viable. Microcode liberated ISA designers from simplicity: as bigger control stores became possible, increasingly complex ISAs became feasible.

As memory became cheaper and memory footprint of code became less of an issue, designs favouring a simplified hardware design without microcode and facilitating aggressive pipelines – even if at the cost of needing more memory – became a more viable option. The Reduced Instruction Set Computer (RISC) [34] movement consequently arose. Also feeding into this was that semiconductor memories replaced magnetic core memories, so it was no longer possible to make a small control store that was many times faster than main memory and control store was no faster than a cache [33].

The RISC movement was to some extent inspired by Seymour Cray's designs while at Control Data. The CDC 6600 is credited with being the first supercomputer as well as presaging RISC ISA principles [2]. Cray's later designs when he started his own company exploited the invention of semiconductor memory to the full. Aside from adding vector instructions and registers, the Cray-1 used what was then a large static RAM (SRAM) main memory, divided into 16 banks[2] [41]. In the remainder of this paper, when I refer to a "Cray" architecture, I mean a classic vector design, not any later designs that may have appeared under the Cray name. Cray in this sense has become a descriptive term rather than a name of a specific product.

Moore's Law is a specific example of a *learning curve law*: essentially a law of competition. If all competitors expect an increase of N% per year on some metric, they all aim for that. If they aim too high, they risk their new design being ready too late. If they aim too low, they risk losing market share to the leaders.

In general terms, if C(q) is the metric of interest for making the qth item in a series of improvements and C(1) is the measure of the first, for the parameter of learning p, Equation 1 defines a learning curve [50].

$$C(q)=C(1)^{-p} \quad (1)$$

Moore's Law is the most famous example but trends in dynamic RAM (DRAM) are equally important. While density drives speed of logic, in DRAM density mainly drives capacity. Consequently, there is a growing CPU-DRAM speed gap, long predicted to run into the *memory wall*, where CPU speed improvements will be masked by memory access delay [48]. Added to this, DRAM organization is becoming increasingly complex, with timing of refresh yet another issue to take into account for minimum latency [5]. The memory wall was to some extent evaded by the shift to multi-core designs with lower clock speeds but the underlying problem is still there and an over-CPU design does not help with balancing DRAM latency with CPU speed.

Across the industry there are other learning curves of interest such as improved power management, improved battery life and reduced network switching latency. However, for this paper, memory and CPU trends are sufficient to illustrate the point: an over-CPU design is not a good use of available transistors.

Another trend is the growing general-purpose use of GPUs (GPGPU). This approach is opportunistic: GPUs offer a lot of computational power and are relatively inexpensive compared with a custom high-performance CPU. However, they are widely known to be difficult to program [11]. I have argued elsewhere that we will reach a GPU endpoint: a faster GPU will not be useful up to the point where human senses are saturated. Once that point is reached, speed enhancements of GPUs will only benefit general-purpose use. I further argue that once this point is reached, a sub-optimal GPU that is easier to program for general-purpose use may be a better design trade off [25]. While Intel explored part of that design space with the abandoned Larabee project, that CPU was based on a modest pipeline with added graphics in-

[2] Large, in its day, meant 64 Mibytes.

structions, rather than a reasonably strong computation engine [43]. The better solution in my view is to start with a known high-performance ISA and, if necessary, extend it with graphics operations.

3.1 Other Related Work

The RISC-V project provides open designs for a RISC architecture drawing on lessons of older designs, a starting point for developing new ideas unencumbered by licensing considerations [2]. There are various extensions of the basic RISC-V ISA, including vector instructions inspired by Cray designs [40].

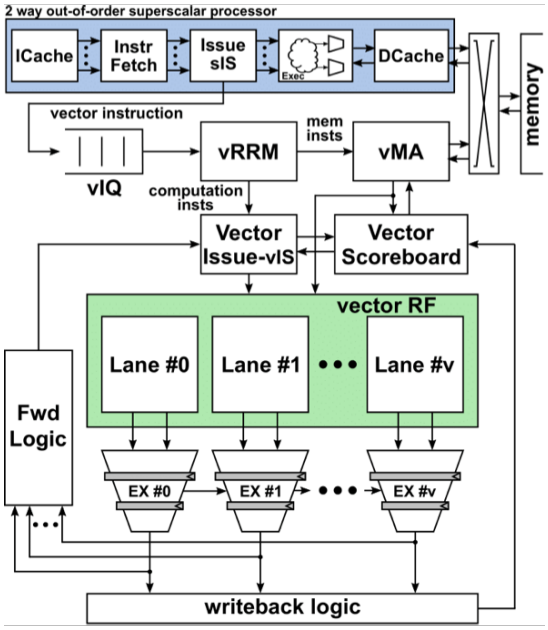


Fig. 2. Moore's Law trend showing major inflection points. When IBM made their record loss, RISC designs such as MIPS R4000 appeared and Intel's Pentium was about to launch. The iPhone required a good enough ARM CPU. Apple M1 Max has 57-billion

A growing number of projects is building on the RISC-V vector architecture [21, 47, 31, 36]. Allied to this is work on improved vector code generation in the LLVM compiler project specifically for the RISC-V vector ISA [1][3].

It is therefore not a sticking point for a project to design a Cray-like vector CPU as the RISC-V free CPU project has already worked on that [31] – see key components of one design, RISC-V^2, in Figure 2. RISC-V^2 includes a 2-way superscalar pipeline with out of order execution, much the same as each single core in the original single-chip multiprocessor proposal. So the major work in the project is designing the memory system and the software layers. Another project has an even more complete

[3] The GCC toolchain is also available but LLVM generally has better performance [38].

RISC-V vector design [36] so it is increasingly becoming a matter of choosing the one closest to requirements as a starting point.

Where it comes to balancing CPU and on-chip memory, an idea that has been around for some time is processing in memory (PIM) [18], also sometimes called intelligent RAM (IRAM) [32].

Why has this idea not taken off? A clue is in the Terasys design [18], where relatively modest CPUs were incorporated into DRAM. DRAM and CPU logic are built with different processes and combining the two on one die involves design compromises, making it difficult to get the best possible DRAM or best possible CPU design on the same part. Consequently, recent work on PIM [28] has focused on tight packaging of DRAM dies with CPU dies (such as 3-dimensional stacking – see also Apple's SiP packaging [27] referred to in Section 2), more complex DRAM organization that can mitigate off-chip delays and new alternatives to DRAM, none of which have yet become available at scale.

3.2 Putting it all together

The overall proposal here is to combine free CPU work of the RISC-V project with the PIM idea. Taking advantage of the large number of transistors of recent designs (the "inflection point"), instead of implementing PIM using DRAM, and hence limiting the capability of the CPU, using SRAM allows an aggressive CPU.

Unlike the trend of contemporary designs, the balance is shifted to more relatively high-speed memory on a die, rather than more CPU.

4 A More balanced design option

Given the potential for doing something different and new now that a die with more than 50 billion transistors is viable, should we be looking at more of the same, or looking for a new idea?

The answer, I propose, is reviving an old idea in a more efficiently packaged and hence lower-cost form.

My idea is that a reasonable use of over 50-billion transistors is to use most of them for SRAM on a chip with a single processor close to the design of a Cray vector machine.

Why SRAM and not DRAM?

While DRAM has many modes to improve speed of access [14], it cannot achieve the same flexibility and overall speed as SRAM. Part of the speed difference arises from the different electronics. SRAM uses transistors to store bits. DRAM stores a bit using a capacitor, which needs to be refreshed. Switching time is inherently slower than a transistor. Another issue is that the fabrication technology is different, making it harder to include logic and DRAM on one chip, while SRAM uses the same logic as a CPU.

Such a design would be far simpler than a typical over-CPU architecture. Multiple banks of SRAM on one chip would not require complex logic. A single vector CPU

with out of order execution of scalar instructions would be similar to the Cray-1. With a large amount of on-chip SRAM, the CPU would not be memory-limited.

Why Cray? Cray's designs were very competitive in their day, though expensive to build as they used a large number of discrete components and needed very efficient packaging to minimise communication latencies, hence the very compact design particularly of the early models [3]. Vector compilers became very efficient and some of the ideas like multiple banks of SRAM are not particularly difficult to implement on a single chip.

How much SRAM?

A die with over 50 billion transistors could support 1 Gibyte of SRAM with space left over for a CPU. With 6 transistors per bit, 1 Gibyte of SRAM requires 51.5-billion transistors. This is about 90% of the transistor count on an M1 Max die, leaving nearly 10% of a similar-sized die for CPU logic. However, the exact amount of SRAM that would be optimal would depend on how fast it could be accessed. That is a function of wiring delay as well as switching speed. Both of these factors improve as feature size reduces. Apple's M1 Max is built with a 5nm process and 4nm processes are already available[4].

A reasonable design goal is for SRAM to be accessible in 2 clock cycles. This means that any memory access can be handled in two pipeline stages. A multi-banked SRAM can accommodate a mix of different access types, including vector access and instruction fetches. If 2-cycle access is not feasible, caches will still be needed for scalar operations and instructions, but vector accesses could access the SRAM directly.

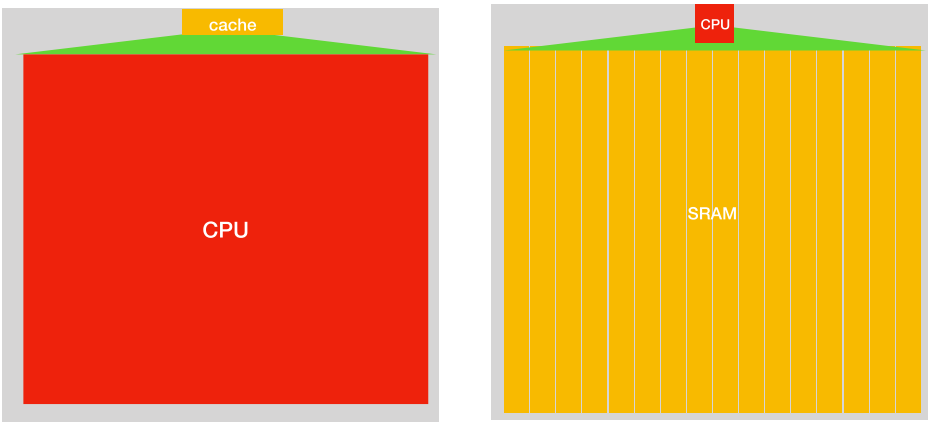
To give some idea of speed, a commodity SRAM from Renases (one of the larger manufacturers of commodity SRAM) is available with a 6 ns clock cycle time and can set up a read or write including the address in one cycle and transfer data in the next cycle. It can also deliver data in burst mode, with up to 4 accesses for one addressing operation [39]. This kind of SRAM is only available in relatively small units, up to a few mebibytes, since the cost per bit is so much higher than DRAM. However, in this proposal, chip space that would otherwise be used for logic will instead be used for SRAM, so provided the result is at least as good as an over-CPU design with the same number of transistors, a big SRAM is not an extra cost.

Exactly how fast an SRAM memory is depends on how it is organized. Relatively large caches on recent Intel (64 MiB) and AMD (512 MiB) server-class CPUs for example have a read latency of about 20ns in the L3 cache [46], but the L3 cache has a more complex access protocol than an ordinary memory, particularly as it is part of a multiprocessor design. What we can be sure about however is that the proposed on-chip SRAM will be faster than an off-chip DRAM.

Using multiple banks that can be addressed and accessed in a pipelined fashion or simultaneously can increase the effective speed, and an on-chip SRAM will not incur off-chip delays. On-chip SRAM could also be potentially accessed with multiple

[4] Characterising a process by nanometers is not strictly accurate as processes vary: transistors per mm2 is proposed as an alternative [9] though that does not capture the fact that some dies may have a larger ratio of interconnect to logic.

modes of accessing banks, allowing e.g. streaming for vector loads, while also doing scalar loads out of other banks.



(a) Mostly CPU (b) Mostly SRAM

Fig. 3. Comparison of die area used in an over-CPU design like M1 Max vs. Crayon. Layout is conceptual, to illustrate differences in allocation of transistors.

If there are 16 banks as in the Cray-1, each bank in a 1 Gibyte SRAM would be 64 Mibytes. Making the conservative assumption that a 6ns cycle time is the best achievable with an SRAM of this size, overlapping bank accesses would result in an average access time of $\frac{6}{16}$=0.375ns, corresponding to a clock rate of 2.67GHz. From here on, assume memory cycles are 6ns and CPU cycles are 0.375ns. The effect of 16 banks is to allow up to 16 memory operations to occur in parallel, resulting in those 16 memory accesses completing in 2 memory cycles instead of 64. If access to 16 banks is pipelined, the first access will take 2 memory cycles totalling 12ns or 32 CPU cycles but each thereafter can occur on the next CPU cycle. I use 16 here for illustrative purposes; with an on-chip SRAM there is no reason not to have a higher number of banks.

Separately addressed banks have other benefits. Interference between code and data movements can be reduced, and a mix of different types of data movement including vector and scalar loads and stores can be accommodated.

Using either the pipelined or simultaneous access – or both – would not be difficult to design with SRAM and CPU on a single die. Design of the memory controller logic could be tightly integrated with the CPU and memory. While DRAM may include many modes that appear to fit the requirements of diverse forms of access including streaming and even internal bank structure, it is difficult to achieve the theoretically available performance in practice [14].

Putting it all together, I propose a Cray-style RISC plus vector CPU with a sizeable (e.g., 1 Gibyte) SRAM memory on the same chip, called *Crayon* (for Cray on a chip).

It should be possible to implement all the logic required for the CPU in 100-million transistors (noting the aggressive AMD design mentioned in Section 2 had less than

that but lacked a vector unit). If that is the case, logic would be about 0.2% of the transistors and SRAM 99.8%.

Fig. 3 Illustrates how die usage differs in an over-CPU design like M1 Max, in which about 2% of the transistors are used for caches, vs. a Crayon design, where the CPU is less than 1% of die area with most of the rest used to for SRAM. The illustrations are not meant to be floor plans: in a design like M1 Max, CPUs and caches are not grouped as a single entity. They are however drawn approximately to scale to illustrate the difference in design focus.

4.1 Uses

It is useful to consider possible uses of a CPU with a large included SRAM. A proper detailed study of performance is justifiable if there are clear cases where it could be a good idea.

Design variations. One Crayon on its own would have a substantial memory but one that is far smaller than a typical standalone computer. A more powerful system could be built in various ways. If more processing was needed, more than one CPU plus SRAM Crayon chip could be used. If more memory was needed, external DRAM could be added as another level of memory – possibly as a fast paging device [26]. Since any external DRAM would not be accessed as often as with an over-CPU design, off-chip delays would not be as big a bottleneck.

Closely-coupled Crayon parts forming a multiprocessor node could packaged much like a typical stick of DRAM. For example, 16 such units would contain 16 Gibytes of SRAM and would make for a powerful personal computer. Such nodes could be clustered to form a large-scale system – for example, 1024 Crayons could be configured using 64 such nodes, totalling 1 Tibyte of SRAM and 1024 vector CPUs. Such combinations with a fast interconnect could be seen as a non-uniform memory (NUMA) design [22], or use a distributed memory or distributed shared memory [29] architecture.

Some of these ideas would need operating system work, like treating DRAM as a paging device, or implementing distributed shared memory. In the simplest case, each Crayon device could function independently as part of a network of devices or on its own for an application that did not need more memory. Each node would be a Crayon chip, power supply and network interface.

There is considerable work on speeding up network connectivity because of the memory-speed bottleneck in over-CPU designs [35, 17, 24]. Since their problem is harder than Crayon's, there is no need for special innovation in interconnects to implement a Crayon design.

Use cases. One type of use case is for read-once data streams. A single device of this kind with a network interface could process a stream of data that has to be discarded once processed and pass on the results either to another device or to storage.

Square Kilometer Array (SKA) [6] is an example – data produced when it is working at scale will be too large to store and the faster it is processed, the more can be

extracted before the data must be discarded. A network of Crayon devices could fill this need. A Cray-style CPU would be well-suited to the sort of computations needed like Fast Fourier Transforms and deconvolution [42]. Astronomy applications use GPUs; speedups over conventional CPUs are typically a small fraction of the available parallelism [7, 8]. This points to a need to balance memory and CPU so it would be worth exploring more such applications as workloads of interest for a Crayon design.

Another example is a malware scanner or a firewall. Data passing through needs to be checked quickly and passed on if no problem is detected. The throughput characteristics of a Crayon device would support such a use. The need for wire-speed firewalls is extending to new applications like automotive [49] – so a relatively low cost device capable of processing complex rules in real time could have a large market. For embedded applications, a variant with a smaller SRAM would fit a lower cost and lower energy requirement.

Many high-performance computing applications were implemented successfully on vector computers, and there is ongoing research into achieving good speedup on such architectures, with good speedups reported for most of the SPECfp2006 benchmark suite [19].

In general, any application that is reasonably partionable and for which vectorizable code can be written could fit a network of Crayon devices. The big advantage over traditional large-scale supercomputers is that the design is scalable. The advantage over commodity CPUs is that a vector design with a high-speed memory is a proven architecture for high-performance computing.

5 Conclusions

The basic principles for designing a Crayon device are relatively straightforward. The Cray-1 and successors contain a range of useful ideas that would be much easier to implement on a single chip. While 1 Gibyte is big compared with RAM on early Cray machines, it is not big by current standards. Nonetheless a Crayon design could be a good starting point for scaling up to large-scale systems. A system with 1024 Cray-class CPUs and 1 Tibyte of SRAM is a substantial computational resource. If this is a good idea, why did the original Cray vector line die out? It had no mass market. If the next big design didn't sell, the company risked bankruptcy. If the proposed Crayon part had sufficient applications, this problem would fall away.

Compared with the original Cray designs, Crayon is a scalable building block and does not require complex manufacturing to build a whole system. A node for a highly partionable computation can be as simple as a Crayon chip, a network interface, and a simple power supply.

Another important detail is power consumption; there is no reason in principle that a Crayon should not be competitive with an over-CPU design. SRAM can wake up fast from low-power modes for example, so the entire memory need not be running on full power at once.

What I present here is a starting point for re-evaluating the trend towards cramming more and more CPU onto each chip. There are many other ways the vast number of transistors available on a die could be used. However, this project focuses on the detail of a Crayon design to evaluate how far it can be taken. Issues to consider include how fast on-chip SRAM can reasonably be accessed, whether caches are still needed or whether a multi-banked cache obviate that, and details of the instruction set design and how they interact with the memory system.

Getting all the details right of course is nontrivial. The operating system will need to understand the memory hierarchy (that depends how it is designed, e.g., a DRAM layer functioning as a paging device, or distributed shared memory would require more work than a standalone node or a NUMA architecture). Provided that the RISC-V vector architecture is used, compilers will not be a problem. Overall, compared with the original Cray vector machine project, implementing Crayon should be relatively easy.

Future work includes a more detailed design, performance studies and more details analysis of potential use cases.

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Why Proprietary Blockchains Are Not Suitable for Online Voting!

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Abstract. This paper explores the potential of open-source Blockchain technology as a solution to the security, reliability, and transparency issues that have thus far prevented the widespread adoption of online voting. Elections are a crucial component of a country's democracy, and a lack of trust in electoral systems can have significant consequences. With free and fair elections dropping to just 45% of elections across 169 countries globally between 2001 and 2011 and Freedom House noting a decline in democratic freedom with this decline reaching its nadir in 2020, the potential for online voting with Blockchain technology to revolutionise democratic processes is becoming more apparent. This article explores the literature associated with Blockchain, including its background, architecture, characteristics, permission models, and limitations. It also explores the literature associated with voting, including the characteristics of a fair voting system, the problems associated with voting, and electronic voting. Additionally, it examines the use of Blockchain technology in Sierra Leone, Russia, and Romanian elections and highlights why open-source Blockchain technology is critical to online voting. The paper argues that an open-source Blockchain could provide unparalleled security and transparency while ensuring the system is accessible to all voters.

Keywords: Blockchain, Voting, Electronic Voting, Internet Voting, Blockchain in Elections, Open-source Blockchain.

1 Introduction

Elections form a crucial part of a country's democracy, and widespread doubt in election results and lack of fairness can be devastating. It undermines the elected government's legitimacy, damages international relations, and leads to social unrest in the country. Today, the lack of trust in countries' electoral systems is becoming more evident, with free and fair elections dropping from 70% of elections between 1975 and 1985 to just 45% between 2001 and 2011 across 169 countries globally [9]. According to a study conducted by Freedom House, a democratic decline began in 2006 when it was observed that more countries' democratic freedom was on the decline than on an upward trend, with that decline reaching its nadir in 2020. As of 2022, it

was observed that 34 countries saw improvements in their democratic freedoms while 35 saw declines in the same area [18]. As the world becomes increasingly digitised, the potential for online voting to revolutionise the democratic process is becoming apparent. However, concerns about the security, reliability, and transparency of online voting have thus far prevented it from being widely adopted. One potential solution to these issues is using open-source Blockchain software, which could offer unparalleled security and transparency while ensuring the system is accessible to all. This article starts by discussing the background of Blockchain technology, its architecture, characteristics, permission models, and limitations. This is followed by a discussion on voting, the characteristics of a fair voting system, problems associated with voting and electronic voting, why proprietary Blockchain technology in Sierra Leone and Romanian elections failed, and why open-source Blockchain technology in Russian elections was successful despite its failure. Lastly, it is debated why open-source Blockchain technology might hold the key to successful online voting.

2 Blockchain

2.1 Background of Blockchain

The timeline of Blockchain history can be summarised in Fig. 1.

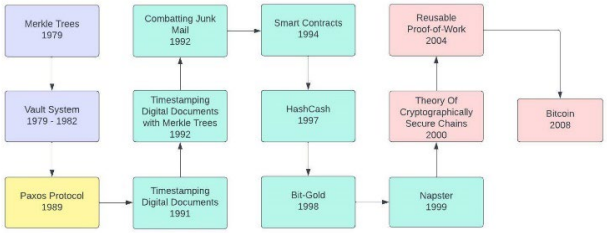

Fig. 3. History of Blockchain Technology

Dr Ralph Charles Merkle, a computer scientist, patented the idea of Merkle trees in 1979 [43]. They are a fundamental building block in many sophisticated authentication schemes [36] and are created through a recursive process by repeatedly calculating hashing pairs of nodes until there is only a single hash left, which is known as the root hash or the Merkle root, and it is a summarised hash value [43]. The vault system, published in a memo in 1979 by Dr David Chaum, and subsequently in his PhD thesis in 1982, proposed every element found in Bitcoin except the Proof of Work concept. Dr David Chaum described the design of a distributed computer system that can be set up, maintained, and trusted by individuals who do not typically trust each other [11]. In 1989, Leslie Lamport came up with the idea of the Paxos protocol [26]. The theory was based on the Aegean Island of Paxos, in which a lack of devotion to civil duty led to a part-time government comparable to modern-day fault-tolerant distributed systems [26]. The Paxos algorithm allows a group of computers in a distributed system to agree on a single value [26]. The Paxos algorithm was designed to

be failure-resistant and resistant to attacks, as it allows the computers to continue the process even if some of them are not available or are behaving maliciously [27]. In 1991, Dr W Scott Stronetta and Dr Stuart Haber raised the prospect of a world in which all information, such as audio, images, videos, and text, were digitised and raised the question of how to certify when a document was created or last edited, and this led to the idea of time-stamping digital documents [19]. They proposed three solutions: the "naïve solution", the "trusted time-stamping service", and the "two time-stamping schemes", which improved on each other [19]. In 1992, Dr W Scott Stornetta and Dr Stuart Haber worked with Dr Dave Bayer to improve the efficiency and reliability of time-stamping documents using Merkle Trees [6]. In 1992, the first computational technique for combatting junk mail was presented by Dr Cynthia Dwork and Dr Moni Naor [28]. It aimed to combat junk mail and control access to a shared resource by requiring a user to compute a moderately difficult but not intractable function to gain access to the resource and therefore prevent frivolous use [12], thus every time an email was sent, the computer spent a few seconds solving a puzzle before the email was sent [35]. In 1994, Nick Szabo coined the term "Smart Contract" [32]. The idea was to convert traditional contract clauses into code that could be embedded into software or hardware to enforce the contract terms without a third party or trusted agency [32]. In 1997, Dr Adam Back proposed the idea of Hashcash [35]. The idea behind Hashcash was to throttle systematic abuse of un-metered Internet resources such as email and anonymous remailers [4]. In 1998, Nick Szabo developed the idea of "Bit-Gold". The idea behind Bit-Gold was to compute a string of bits from a string of challenge bits (challenge string) using "Proof-of-Work" functions. The resulting string of bits would be the proof of work [45]. Napster came into effect in 1999 and was a Peer-to-Peer (P2P) file-sharing application that allowed its users to trade music by uploading their MP3 files to an online library accessible by consumers for free [2]. Napster was the first mainstream Peer-to-Peer (P2P) network [17]. Modern-day Blockchains operate on a P2P network where no node has greater authority than any other node, and participants can join and leave the network as they please [42]. In 2000, Stefan Konst published his theory of cryptographically secured chains and his idea of its implementation [47]. In 2004, Harold Thomas Finney II developed the idea of Reusable Proof of Work (RPOW). The scheme functioned by accepting a non-fungible or non-exchangeable Hashcash-based POW token and producing an RSA-signed token that could be passed from user to user. This addressed the double spending problem [15]. The first Blockchain implementation was in 2008 when a pseudonymous person named Satoshi Nakamoto implemented the technology to create the first cryptocurrency called Bitcoin [20]. In August 2010, a vulnerability was found in the Bitcoin protocol, and this caused certain users to take advantage and make payments with enormous amounts of 184 billion Bitcoin despite the level of security. The Bitcoin authority spotted the transaction, resolved the bug, and reversed the Bitcoin transaction [31].

2.2 Architecture and Components of the Blockchain

Blockchain is a sequence of blocks that holds a comprehensive list of immutable transactions [1]. Blockchain technology uses a decentralised architecture based on node consensus algorithms to verify data, distribute computing data storage on crypto blocks, and use smart contracts to program data [39]. The components that make up a Blockchain include cryptographic hash functions [49], transactions [49], asymmetric-key cryptography [39], addresses [49], wallets [49], ledgers [49], nodes [40], and blocks [49]. These components shaping the architecture of Blockchain enable a set of unique characteristics with significance for various applications.

2.3 Characteristics of Blockchain

Blockchain technology can be used for various purposes depending on the type of Blockchain and its implementation. Some of the characteristics are detailed below:

- **Anonymity**: Users that interact with the Blockchain are assigned an address generated by the system to mask the user's identity [40].
- **Auditability:** This means transactions can be tracked and verified on the Blockchain [40].
- **Decentralisation:** This means that Blockchain technology does not rely on a centralised transaction authority to validate transactions [40].
- **Integrity**: Blockchain technology protects against unauthorised changes in data, leading to data integrity [40].
- **Persistency**: Transactions that are recorded in a Blockchain ledger are considered to be persistent as they are spread across the network and are synchronised to other nodes that control and maintain their records, as long as the transaction is verified, and a majority of the nodes agree with the transaction [48].
- **Privacy:** Blockchains that use specific protocols may allow a certain level of privacy to safeguard potentially sensitive information [40].
- **Public verifiability:** Any user can quickly validate the Blockchain's correctness by simply communicating with other nodes to obtain information about the Blockchain's correctness [40].
- **Redundancy:** Blockchain relies on decentralised architecture to duplicate data across all writers to achieve data redundancy [40]. This ensures that the data is protected and that there is no unintended data loss.
- **Transparency**: Blockchain data is consistently updated for verifiability [40].
- **Trust Anchor:** A trust anchor is an entity responsible for granting read and write access to a system and can therefore grant and revoke rights to the system [40].

2.4 Blockchain Permission Models

Blockchains can be classified into two, namely permissioned Blockchains and permissionless Blockchains [40]. A permissioned Blockchain only allows particular users to publish blocks [49]. A permissioned Blockchain network is not entirely trustless

since a central authority can roll back transactions, or if most participants choose to do so [29]. Permissionless Blockchains are decentralised, open to everyone, and can be connected to and abandoned by any peer as a writer or reader [40]. Permissionless Blockchains are often open-source software and are freely available to anyone wishing to download it. Since these Blockchains are open to everyone, malicious users may try and publish blocks to subvert the system. To prevent this, permissionless Blockchains often use a consensus system or multiparty agreement, requiring users to maintain or expend resources when publishing blocks [49].

2.5 Blockchain Limitations

While Blockchain is one of the most revolutionary technological advances in the modern era and has been adopted by various industries such as finance, health care, supply chain management, etc., like all other technological advances, it still has challenges and limitations that must be addressed [40]. Some of these challenges and limitations are discussed below:

- **Scalability**: As transactions increase daily and new blocks are generated, scalability eventually becomes problematic [40].
- **Privacy leakage**: Blockchains do not guarantee transactional privacy [40] since balances and transactions of each public key are publicly visible [1].
- **Selfish mining:** This relies on a small amount of hash power to make the network vulnerable, leading to Blockchain insecurity. This means that mined blocks are kept on a private branch and are not broadcast to other users. The public could access these secret blocks only under certain conditions [40].
- **Energy consumption:** Validating transactions on a Blockchain network using certain consensus algorithms, such as Proof-of-Work, requires a lot of computational power to solve a mathematical algorithm leading to high energy and power consumption [40].
- **Oracle problem:** Problems may occur when Blockchains need to interact with the real world as there is no way to validate that the inputted data reflect real-world events [49].
- **51% attack:** This occurs when 51% of the nodes collude to generate fake blocks or reverse transactions already confirmed on the Blockchain. The higher the computational power, the quicker the blocks are generated. Thus, genuine, honest nodes cannot compete for a fair version of the Blockchain as nodes would only believe in the longest chain [41].
- **Blockchain governance:** When disagreements pop up between the governors of the Blockchain network, it leads to a fork in the network due to the Blockchain protocol being updated [40].

3 Voting

The ancient Greeks were the first to create a democracy in approximately 508 B.C. [44]. The first recorded popular election of officials to a public office by majority vote dates back to the Ephors of Sparta era in approximately 754 B.C. [51]. Modern-day elections have their roots in the gradual emergence of representative governments in 17th Century Europe and North America. In the 17th Century, the Middle Age's all-encompassing idea of representation changed and gave way to a more individualistic concept, making the individual the critical unit to be counted [16].

3.1 Characteristics of a Fair Voting System

A voting system needs to possess the following characteristics to be considered a fair voting system [14]:

- **Integrity**: No vote can be changed during elections [14].
- **Eligibility**: This means that only eligible voters who are registered, over the legal voting age, and have not previously cast their ballot in a specific election can cast their ballot [14].
- **Availability:** This refers to the ability of the system to remain available in real-time during the election [14].
- **Fairness**: This means that partial results from the election should not be published before voting ends so that voters do not modify their decision based on partial results [14].
- **Anonymity**: This implies that a voter's identity should remain anonymous [14].
- **Correctness:** This means that the election process results must be tallied correctly to be published [14].
- **Verifying results:** This means that the results are verified, and the system introduces a way of verifying the election results [14].
- **Robustness:** This indicates that the voting system must be able to handle ineligible voters and votes that cause problems and must be able to detect any attackers that take part in any malicious activities and discard their votes [14].
- **Concern of coercion:** A voter should not be able to prove to anyone else that they voted for a specific candidate [14].

3.2 Problems With Voting

While various voting systems have been around for hundreds of years, the integrity and trust in such systems have never been undermined and lacked as much trust as they do nowadays. There are numerous instances of election results being questioned, even in first-world countries such as the United States of America [7, 10]. Elections in Zimbabwe have been contested numerous times with allegations of gerrymandering, vote-buying, coercion, rigging, and many other irregularities since 1990 [33]. Brazil's former President Jair Bolsonaro expressed fears of voter fraud in his 2018 Presidential campaign to pre-emptively cast doubt on unfavourable election results [8]. In Febru-

ary 2021, the Myanmar military justified a coup against its civilian government by alleging voter fraud in its recent election [8]. According to a study conducted on 169 countries' elections (totalling 1114 elections) between 1975 and 2011, there has been a decrease in free and fair elections from 70% between 1975 and 1985 to just 45% between 2001 and 2011 [9]. According to a study conducted by the Freedom House, a democratic decline began in 2006 when it was observed that more countries' democratic freedom was on the decline than on an upward trend, with that decline reaching its nadir in 2020. As of 2022, it was observed that 34 countries saw improvements in their democratic freedoms while 35 saw declines in the same area [18].

4 Electronic Voting

Electronic voting is the process of voting using an electronic device [38]. Electronic devices can be used for the electronic registration of votes, channels for remote voting, and electronic counting of votes. Electronic voting has been used in various forms since the 1970s and has provided real benefits such as reduced errors and increased efficiency over paper-based systems [24]. Electronic voting must follow some basic principles and be as close to traditional voting as possible to ensure it remains compliant with electoral law [30]. This means that electronic voting should be uniform and secret, only eligible voters should be able to cast their ballots, every voter should only be able to cast a single vote, a voter must not be able to prove that they voted for a specific candidate and the collection of votes must be reliable, secure, and accountable [30]. Furthermore, electronic voting should be as transparent as possible to ensure that it can be easily audited by a team of specialists [30]. There are two electronic voting technologies: I-voting and E-voting [23].

4.1 I-Voting

This is the process of casting a vote from any computer connected to the Internet, including computers located at home [38]. Limited trials of voting via the Internet have occurred in countries such as Estonia, Switzerland, France, and the Philippines [38]. One of the most significant advantages of I-voting is that an individual can vote from anywhere worldwide, thus increasing voter turnout. I-voting also eliminates the time-consuming process of visiting a polling station, possibly joining a long queue, and then casting your ballot. In addition, manual counting of votes is a slow and time-consuming process thus I-voting reduces or even eliminates the delay in receiving election results [46]. Despite the advantages of I-voting, it is vulnerable to Denial-of-Service attacks which may make the system inaccessible to the voters who need to use it. In addition, many voters' computers are vulnerable to penetration by different types of malware, which can be used to block or change legitimate votes, resulting in the subversion of the electoral process in a potentially undetectable manner. Another concern about I-voting is that it is vulnerable to vote-selling and voter coercion when voting does not take place in a controlled environment [38]. Voting via the Internet or I-voting can be broken down into three types, namely Intranet voting in polling sta-

tions (voting is performed on a public computer, and the Internet transfers data from the polling station to local, regional, and/or the central electoral authority), kiosk voting (in this method of voting, the electoral process cannot be controlled by public authorities thus, special instruments for electronic authentication are necessary, such as smart cards, biometric security validation, etc.) and Internet voting (allows a voter to vote from home or work remotely without physically visiting a polling station.) [23].

4.2 E-Voting

E-voting is voting using large-scale, special-purpose machines that are held in designated precincts [38]. E-voting can be subdivided into two major e-voting equipment types: Direct Recording Electronic (DRE) machines and Optical Scanning machines [38]. The DRE voting system is composed of a touch screen connected to a computer, ballots are presented to the voter on the touch screen, and they can make their choice, confirm their choice, and cast their ballot [38]. The DRE voting system then directly records the casted ballot and stores the data in its memory. This means that a single machine is used to select candidates, cast ballots, and record the ballots [38]. Optical Scanning Machines work by using Optical Character Recognition (OCR) technology or Optical Mark Recognition (OMR) technology (also known as Marksense) to read and interpret the markings made on a ballot by a voter and then tally those marks to determine the outcome of the election [38].

4.3 Electronic Voting in Estonia

In Estonia, e-voting has been in use since 2005 [3]. Voters in Estonia are allowed to re-vote if they desire. In this case, their previous e-vote is deleted, and only the newest vote is counted. This is done to prevent vote-buying and coercion as illegitimately influenced voters can re-vote once the influence is gone [30]. The e-voting system in Estonia uses the envelope method and works as follows [3, 30]:

1. A voter inserts their ID into a card reader and opens the homepage of the National Electoral Committee.
2. The voter verifies their identity by using the first PIN code of their ID card.
3. The server validates the voters' eligibility using data from the population register.
4. A list of candidates in the voter's constituency is displayed to the user based on their personal identification number.
5. The voter decides; this vote is then encrypted (this step can be defined as the inner envelope).
6. The voter confirms their choice with a digital signature by entering the second PIN code of their ID card (this step can be defined as the outer envelope), and the voter gets a confirmation message that their vote has been recorded.

At the end of the process, the inner envelope data is forwarded to the National Electoral Committee which decrypts the anonymous vote to count it. The outer envelope

data is used to compile a list of voters who voted based on their ID number. This list is then forwarded to polling stations to ensure that voters who voted electronically do not double vote at a polling station [30].

5 Use of Blockchain Technology in Elections

5.1 Sierra Leone Presidential Elections – 2018

On the 7th of March 2018, Sierra Leone became the first country in the world to use Blockchain technology to verify votes in an election [37]. Agora, a Swiss-based Blockchain company [22, 50] acquired permission from the National Electoral Commission in Sierra Leone to digitise 250 of Sierra Leone's 446 electoral wards [50], totalling up to ~400000 ballots [25]. Agora's staff manually digitised these ballots, generated final tallies for the districts, and published the final results five days before the official results were released. Not only were the ballots digitised, but they were also encrypted, anonymised, and stored on the Blockchain before the actual counting of the ballots was completed [50]. The data, which was anonymised using encryption processes, were manually recorded on Agora's Blockchain platform, where it was added to separate data blocks that represented the various districts involved in the test run. The data was then added into an exportable CSV file which was hashed via Merkle Trees. The data was imported into Agora's permissioned Blockchain and stored as key-value pairs. The top hash of each block was then recorded onto the Ethereum Blockchain as a smart contract to ensure that votes could not be altered by ensuring that the hashes of the two Blockchains corresponded [50]. Agora's election results were made publicly available online and were consistent with the NECs official election count, thereby making the trial run of Agora's proof of concept vote tallying system a success [50].

5.2 Moscow's E-Voting System – 2019

Moscow IT Department built a remote voting system that used a variant of ElGamal encryption over finite fields [13]. The system was tested on the 8th of September 2019 for the local Parliament elections, and to ensure transparency of the election process, the source code was published on GitHub for everyone to access (https://github.com/moscow-technologies/blockchainvoting). The Blockchain stores votes, with each transaction representing a vote. The voting procedure required voters to register by filling in account details with personal information and then visiting the office to validate their identity. The voting process was based on a unique link shared with the voter. To get it, the voter had to provide a code that was sent via SMS and was only valid for 15 minutes. If the voter had not decided by then, the ballot would expire. Votes were then added to the Blockchain with a random delay to ensure that it was challenging to discover the voters' identities. In addition, to achieve anonymity during the voting process, a single-use key was created to sign a transaction and destroyed after the vote was cast, meaning no link existed between the vote and the voter. Election fairness was also achieved by encrypting the results during voting.

Voters were allowed to verify that their votes were cast correctly, and after the end of the voting, any voter could join the Blockchain network and count the votes [5]. Several weaknesses existed, such as the ability to compute the system's private keys based on its public keys, and the ability of a voter to decrypt their vote without waiting for the election commission to start the official vote count – this was done using the shared key between the voter and the election committee [13]. Ultimately, the project was deemed unsuccessful due to the security requirements as a result of the vulnerabilities in the system [13].

5.3 Romania National Elections - 2020

Romania was the first country within the European Union to use a Blockchain-based voting reporting tool for national elections. On the 6th of December 2020, Romania held national Parliamentary elections that used Blockchain technology to guarantee the integrity of the election and increase its transparency by using a system implemented by the Special Telecommunications Service (STS). The government aimed to ensure real-time data on voter attendance and that the votes could not be tampered with [21]. The technology did not allow the alteration or modification of data that was recorded during the election process. Even the system administrators could not modify any data [13]. The Romanian system was built by the STS from scratch and is based on closed-source, proprietary code, and it is fully centralised and runs on a single logical node that the STS runs [21]. The system worked by having a backend system that would receive individual votes from SIMPV (system for monitoring voter turnout and prevention of illegal voting) in real-time, and polling station reports from SICPV (system for centralising the minutes) would notarise them while exposing a lightweight interface (available at https://voting.roaep.ro/) and open APIs to allow anyone to observe the election while it unfolded and allowed the contents of the SICPV and SIMPV databases to be transparent, as users could access and inspect the data in real-time, though all the data was immutable [13]. The Parliamentary elections in Romania in 2020 took just 1 hour and 37 minutes to validate all the votes using Blockchain technology, which makes it well suited to use for efficient elections [13]. However, Romania still has a long way to go to allow voters to record, manage, count, and check votes by holding a copy of the voting record [21].

6 Discussion

Popular implementations of Blockchain technology, such as Bitcoin, are open-source [31]. Despite the issues Bitcoin has faced since its inception in 2009 [20], such as the vulnerability in its protocol in August 2010 that allowed users to make payments with enormous amounts of Bitcoin [31], Bitcoin has grown to become a multi-billion-dollar industry, all while the code that runs it is freely available on the Internet. Characteristics of Blockchain technology such as anonymity, auditability, decentralisation, integrity, persistency, privacy, public verifiability, redundancy, transparency, and trust anchor [40, 48] make it well suited to satisfy the criteria for a voting system to

be considered fair such as integrity, eligibility, availability, fairness, anonymity, correctness, verifiable results, robustness, and concern of coercion [14]. Successful Blockchain voting trial runs such as Blockchain vote verification in Sierra Leone's 2018 Presidential and Parliamentary election [37] and the Romanian Parliamentary elections in 2020 [21] have proven to speed up the tallying process and increase trust within the electoral system. Blockchain voting failures, such as the 2019 local Parliamentary election in Russia [13] have proven the need for these voting systems to be open-source as researchers can identify and test vulnerabilities within the system that can be patched, thus strengthening the system and increasing trust in the elected government. Open-source voting systems may allow anyone to verify the code and ensure that the system works as intended. The software is customisable to suit the unique needs of particular voting processes. The software is community-driven, meaning that developers, researchers, and experts in the field can work together and contribute towards developing and improving the voting system, thus eliminating identified bugs and issues before the system is implemented. The use of an open-source Blockchain voting system may also prevent the problems associated with the way elections are currently being conducted with countries such as the United States of America's election results being called into question [7, 10], the numerous irregularities in Zimbabwean elections [33], fear of voter fraud in Brazilian elections and may even prevent coups in countries like Myanmar [8]. Proprietary Blockchain voting systems such as the Romanian Blockchain voting system [21] do not guarantee free and fair elections as countries may purport to use Blockchain technology in their elections when they are not fully utilising it. Hackers could target computer systems that contain the proprietary Blockchain voting system code and manipulate vulnerabilities that would have otherwise been detected had it been open source. There is no guarantee that a person's vote goes to the intended candidate unless the code is open-source and people can validate that the system meets the criteria of a fair voting system such as fairness, correctness, robustness, and verifiable results [14]. However, guarantees need to be made that the same open-source version is used in the elections [34].

This study proposes using a permissionless Blockchain, decentralised, [40] open source, and freely available to anyone wishing to download it [49]. Since permissionless Blockchains are open to everyone to participate in, malicious users who may try and publish blocks to subvert the system are prevented from doing so as permissionless Blockchains often use a consensus system or multiparty agreement, which requires users to maintain or expend resources when trying to publish blocks [49]. Unlike permissioned Blockchains, transactions on a permissionless Blockchain cannot be rolled back by a central authority [29], thus making them best-suited to conduct an election and prevent election tampering by the electoral committee. The 51% attack, common amongst all Blockchain networks, can be thwarted by using unique signatures generated by the polling station where the vote is cast [34], or by keeping track of the region in which the vote is cast.

7 Conclusion

In conclusion, this paper has highlighted the potential of open-source Blockchain technology to revolutionise the electoral process by providing an innovative solution to the security, reliability, and transparency issues associated with online voting. By exploring the literature on Blockchain and voting, the paper has identified the key characteristics of a fair voting system, the problems associated with voting, and the benefits of using Blockchain technology. Moreover, the paper has examined the use of Blockchain technology in Sierra Leone, Russia, and Romania, highlighting why open-source Blockchain technology is vital to online voting. Overall, the paper provides reasonable arguments on why an open-source Blockchain could provide unparalleled security and transparency while ensuring the system is accessible to all, thereby increasing trust in electoral systems and strengthening democracy. The paper, therefore, proposes permissionless Blockchain technology and highlights the advantages of using such a Blockchain for electronic voting.

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Prediction of Traffic Flow in Cloud Computing using ARIMA

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Abstract. One of the biggest challenges for cloud service providers is managing traffic. As more and more companies adopt cloud computing, the amount of data transferred to and from the cloud increases exponentially. This can create bottlenecks in the network, causing delays and even downtime for users. To overcome this challenge, cloud service providers must invest in advanced tools and technologies to manage traffic. These tools can help them monitor network traffic in real-time, identify bottlenecks and congestion points, and optimize network performance to provide a seamless experience for users. The second challenge for cloud service providers is predicting traffic. It can be difficult to predict how much traffic the various applications and services will generate at any given time. This can make it difficult for providers to effectively allocate resources and ensure the efficient operation of their networks. To overcome this challenge, cloud service providers must invest in advanced data analytics tools that could help them predict traffic patterns and usage trends. The objective of this study was to analyze historical multivariate time series data to predict traffic volumes in a network using an Auto-regressive Integrated Moving Average (ARIMA). The results show that ARIMA is not suitable for multivariate time series data. In this regard, a proposal to investigate the use of a combination of machine learning models to best present a suitable data analytic model for network multivariate time series data.

Keywords: ARIMA Models, Machine Learning Models.

1 Introduction

With the rapid growth of computing technology exacerbated by aspects of the Fourth Industrial Revolution (4IR) such as Data 3.0, Big Data, Web 3.0, Internet-of-Things (IoT), etc., network data traffic will increase, leading to congestion possibilities. It is envisaged that by 2050, data will increase 3.5 times globally [1-2]. The latter indicates an alarm for infrastructure demand for handling big data. Cloud computing has been seen as an infrastructure solution for handling and working with such big data [1]. In this regard, this increases data traffic and the lack of network resources within the cloud service providers. Of importance is that cloud computing users are driven away when there are no effective tools for allocating resources to customers [1].

Cloud computing traffic prediction and analysis offer several valuable benefits, including fast execution, continuous web presence, better collaboration, and lower subscription costs [3]. These benefits make it the perfect inspiration for businesses to move their data to the cloud and consider the possibility of predicting the future to manage and provide constant resources to their customers. However, studying the traffic in cloud computing has proved difficult, and these could cost businesses several millions and their network infrastructure [4]. In this context, network administrators must be aware of the latest techniques that will help them keep the enterprise running and its networks operating optimally [4].

Network administrators must maintain the organization's operational status quo and stay current with the latest technology to keep the network running optimally. System administrators must manage control and allocation strategies to improve the system and meet customer needs. In cloud computing, the volatile nature of network traffic makes it difficult to predict the network resources that can meet the needs of all network users at any given time. Service providers cannot allocate resources to meet customer requirements. Inconsistent traffic flow leads to customer complaints about slow system times, application timeouts, and increased bandwidth usage during peak hours [5]. The sequencing of activity streams is important for system administration to ensure systems are online most of the time [6].

In this paper, a proactive traffic prediction model that would help network managers keep up with traffic congestion and accurately estimate future resource needs is investigated. In this regard, the paper’s objective was to study the algorithm used to accurately predict the traffic flow in the network and propose a conceptual solution. The rest of this paper is divided into related work on traffic prediction in cloud computing; problem definition, methods used to conduct the study, evaluation metrics, results of the study, and conclusion.

2 Literature

2.1 Cloud computing traffic flow prediction

Cloud computing traffic prediction plays a critical role in the Information and Communication Technology (ICT) sector. Service providers can accurately predict current

and future traffic levels to help organizations meet their service level agreements (SLAs) and operations level agreements (OLAs).

Cloud computing requires adequate and accurate traffic prediction to meet customer needs and support professional organizations. To predict system traffic in cloud computing, a service provider estimates requests and the total amount of data to be moved for a day [7]. Since an application will need to be moved repeatedly in the future, most of the information and applications should be moved daily [8]. In numerous studies [3-5-7], Activity Stream's predictions were validated and met 85% of expectations. However, there has been no progress in implementing a system that predicts traffic using an application framework [5]. With cloud computing being a continuous process, it is very difficult to make a 100% accurate prediction [9].

The current issue is unusual in cloud computing frameworks. These frameworks move a lot of information in the cloud and can lead to system bottlenecks rather than CPU or storage bottlenecks [9]. An example of these exceptional frameworks is Hadoop and Apache Spark. Advanced administration or scientific computation, such as PC programs, runs on many machines and resides in both open clouds and business or extended data centers [10]. In this regard, a systematic literature review (SLR) to investigate existing literature to identify the techniques and technologies used to predict traffic flow was conducted.

The following research databases were consulted: Association for Computing Machinery (ACM), Institute of Electrical and Electronics Engineering (IEEE), and Scopus.

- The inclusion criteria: All papers published from 2020 to 2023 were included.
- The exclusion criteria: All papers published earlier until 2019 were excluded.

Table 1 presents the SLR results. It shows the method identified, merits and demerits in alignment to the paper topic.

Table 2. The SLR on predicting traffic flow.

Title	Method	Merits	Demerits
Bidirectional Spatial–Temporal Network for Traffic Prediction with Multisource Data	Genetic Algorithm and Particle Swarm Optimization based on spark parallelization optimized Combined kernel RVM (SPGAPSO-CKRVM) [2]	Prediction accuracy	Efficiency negatively impacts the performance of the algorithm in general

Prediction of Bus Passenger Traffic using Gaussian Process Regression	Gaussian Process Regression (GPR) [11]	Prediction accuracy even with limited data and The training and prediction process is much simpler and faster.	Not suitable for interactive real-time applications
Data imputation in IoT using Spatio-Temporal Variational Auto-Encoder	ST-VAE (Spatio-Temporal Variational Auto-Encoder) [22]	Improves the ability of the model to recognize traffic flow patterns.	Delayed user experiences focus only on weekly data
Flight delay prediction based on ARIMA	ARIMA time series model [21]	Prediction accuracy	Not suitable for interactive real-time applications
A network traffic forecasting method based on SA optimized ARIMA-BP neural network.	Simulated Annealing optimized Autoregressive Integrated Moving Average Model Back Propagation Neural Network (SA optimized ARIMA–BPNN) [12]	multiple improvements in network traffic pre-diction accuracy	There is no clear indication of which field the future of optimizing the network infra-structure architecture lies.
Prediction of Monetary Fund Based on the ARIMA Model	ARIMA Model [13]	Improve the accuracy of traffic flow predictions.	There are still some differences between the predicted data and the test data
Transferability improvement in short-term traffic prediction using stacked LSTM network	Traffic factor state network (TFSN) framework [14]	Improve the accuracy of traffic flow predictions.	Difficult to fully explore and utilize the correlation mechanism between traffic parameters.
Traffic Flow Prediction Using SPGAPSO-CKRVM Model	Convolutional neural network (CNN)-based bidirectional spatial–temporal network (CNN-BDSTN) CNN-BDSTN model [15]	The plasticity of adding external factors,	Less precision
Predicting daily streamflow with a novel multi-	ARIMA-GARCH model [24]	improve the accuracy of the	Overestimates the peak values when

regime switching ARIMA-MS-GARCH model		model's daily runoff forecast ARIMA-GARCH	the traffic increases.
Application of ARIMA-RTS optimal smoothing algorithm in gas well production prediction	ARIMA-RTS (Rauch Tung Striebel)	The model can eliminate the influence of asynchrony and hysteresis.	Effectively reduce the error caused by stimulation when predicting.

2.2 Auto-Regressive Integrated Moving Average (ARIMA)

For this paper, the Auto-Regressive Integrated Moving Average (ARIMA) was selected as the first model to be used to conduct this investigation. ARIMA is a model that uses a least-squares estimate of AR coefficients. These AR coefficients can be computed accurately from the autocorrelations in a single cycle. According to [17], ARIMA is divided into three phases: estimation, prediction, and forecasting.

- Estimation: In the ID stage, utilisation and recognition of explanations determine the reaction arrangement and distinguish the suitable ARIMA models. The distinguished proclamation examines the temporal order used as part of later articulations and may distinguish between them by determining autocorrelations, inverse autocorrelations, semi-autocorrelations, and contexts. The option of terminating the silent audit is available when discrimination is required. A review of the detected outlines usually recommends at least one possible matching ARIMA model. The selection allows you to test for uncertain or non-unique ARIMA-placed identities [18].
- Prediction: ARIMA problem discovery phase: use gauge declarations to determine the correct ARIMA model that matches the defined description and configure the rules for that model. Gauge declarations also create unique measurements that help evaluate the effectiveness of the model [14]. Significant testing of the rules determines if some terms in the model are meaningless. Insights into the completeness of the fit help compare this model to other models. The reproducibility test indicates whether additional measurements would provide more data suitable for a more comprehensive model. If diagnostic tests (to retrieve data) indicate model problems, try a different model, and then repeat the significance and completeness tests.
- Forecasting: The estimation phase identifies future estimates of timing and determines specific timeframes for these measures using the ARIMA model created by past or early assessment clarifications.

2.3 ARIMA three stage application

The mathematical model of ARIMA (p, d, q) is shown to be precise; however, there are still some differences between the predicted data and the test data [14]. By combining AR (p) and MA (q), While integrated (k) reflects the separation of raw observations to allow the time series to become stationary, the difference between the real data values and the previous values is replaced with the data values. The finite distinc-

tion of the data points in ARIMA (p, d, and q) is used to transform the non-stationary time series into a steady one. E.g. (1), (2), and (3) demonstrate the mathematical formulation of ARIMA (p, d, q) [18].

$$\emptyset(K)(1-K)^d\, yt = \theta(K)\varepsilon t \quad (1)$$

$$\left(1-\sum_{i=0}^{p}\varphi iK^i\right)(1-K)^d y_t = (1+\sum_{j=1}^{q}\theta jK^j)\epsilon t \quad (2)$$

$$Y_t = \emptyset_0 + \emptyset_1 Y_{t-1} + \emptyset_2 y_{t-2} + \cdots + \emptyset_p Y_{t-p} + \varepsilon_t - \theta_1\varepsilon_{t-1} - \theta_2\varepsilon_{t-2} - \cdots - \theta_p\varepsilon_{t-p} \quad (3)$$

where Y_t and ϵt are the actual value and random error at period t, respectively; $\emptyset_1$ (i = 1,2,.,p) and θj (j = 0,1, 2, . . . ,q) are model parameters; p, d and q are positive integers, referring to the order of the autoregressive, integrated, and moving average parts of the model, respectively. A typical method for identifying p and q is achieved by the implementation of the Autocorrelation Function (ACF) and Partial Autocorrelation Functions (PACF) of the data. The PACF plot helps to decide if the ACF plot can classify non-stationary time series by the maximum order of AR (p).

3 Materials and Methods

3.1 Research Design

The research design that was followed in conducting this study is illustrated in Figure 1. Firstly, cloud computing data source and dataset were identified. In this regard, the cloud computing traffic flow data used in this paper was extracted from Forbes Innovation [15]. It is multivariate time series data presented in exabytes (EB). It was extracted from the measurement made by cloud engineers on an annual basis for eight years (i.e., from 2015 to 2022).

Secondly, a literature search was conducted to determine data analytic models that can help in analysing the extracted multivariate time series traffic flow data. The results of the literature were presented in section 2 of this paper.

Thirdly, in this section of the paper, the design of the chosen traffic prediction model, ARIMA is presented [19]. Lastly, the prediction was conducted, the results are presented and discussed in the next section of this paper.

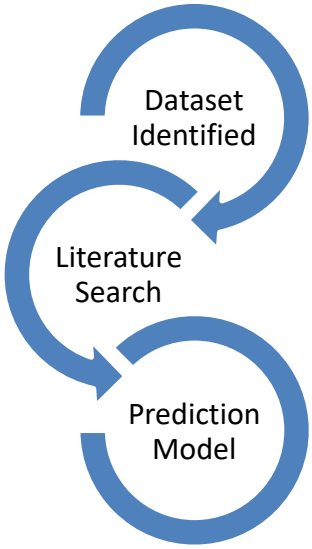

Fig 1: ARIMA design for traffic prediction [14].

3.2 Design of Auto-Regressive Integrated Moving Average (ARIMA)

To produce accurate traffic forecasts, this paper selected the ARIMA method from the literature conducted in Section 2 and used it to gradually reduce the forecast errors. The following ARIMA steps, highlighted in Figure 2, were performed to produce the resulting output.

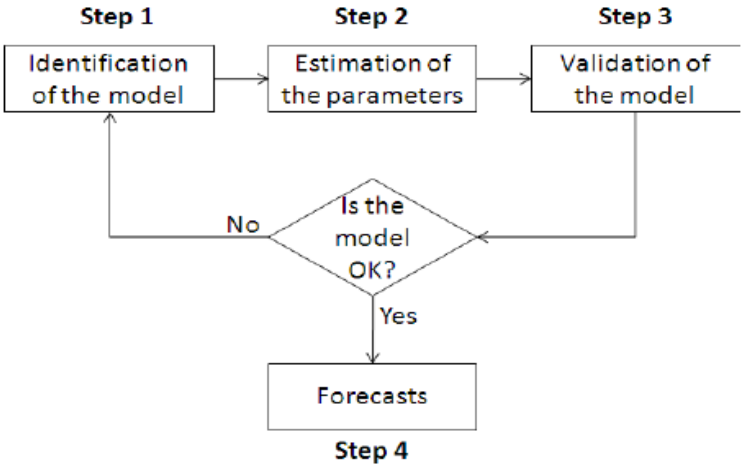

Fig 2: ARIMA processing steps for traffic prediction [14].

The ARIMA processing steps for traffic prediction presented in Figure 2, is described as follows: Firstly, model identification involves capturing the underlying patterns and relationships in the available data so that ARIMA can make accurate predictions about traffic flow in cloud computing for future observations. This process typically involves a combination of theoretical reasoning, exploratory data analysis, model selection criteria, and validation techniques.

Secondly, Estimation of parameters, ARIMA determines the values of various parameters that determine the behavior of the available data, The accuracy and precision of these estimates are critical for ARIMA to make decisions and draw conclusions from the data.

Thirdly, Validation of a model is an essential step to ensure its accuracy and usefulness for decision-making. ARIMA compares the observed data and makes the necessary adjustments to improve its accuracy.

Lastly, ARIMA's predictions are determined by a variety of factors, including the quantity and quality of available historical data, the complexity of the variables to be considered, and possibly external factors that may affect the results.

4 Results

4.1 Evaluation Measures

There are several performance metrics that can be used to measure the accuracy and effectiveness of a time series forecasting model [20]. In this paper, we select the mean absolute percentage error (MAPE), one of the most common measures of forecast accuracy [19]. Regression models can only predict values that are lower or higher than the actual value. Therefore, we use MAPE to evaluate model accuracy. MAPE uses the following formula:

$$MAPE = \frac{100}{n}\sum_{t=1}^{n}\frac{Y_t - P_t}{Y_t} \quad (4)$$

Where Y_t is the actual value and P_t is the predicted value.

4.2 Analysis

The objective of this study was to analyze historical multivariate time series network traffic flow data to predict traffic volumes in a network using ARIMA. In this regard, Figure 3 presents the results of the traffic volume prediction of actual data vs forecast data using ARIMA. During the initial testing, the ARIMA predicted traffic flow did not match or come closer in predicting the actual data. In this regard, the model showed poor performance, and begin to eventually predict the actual data as time progressed.

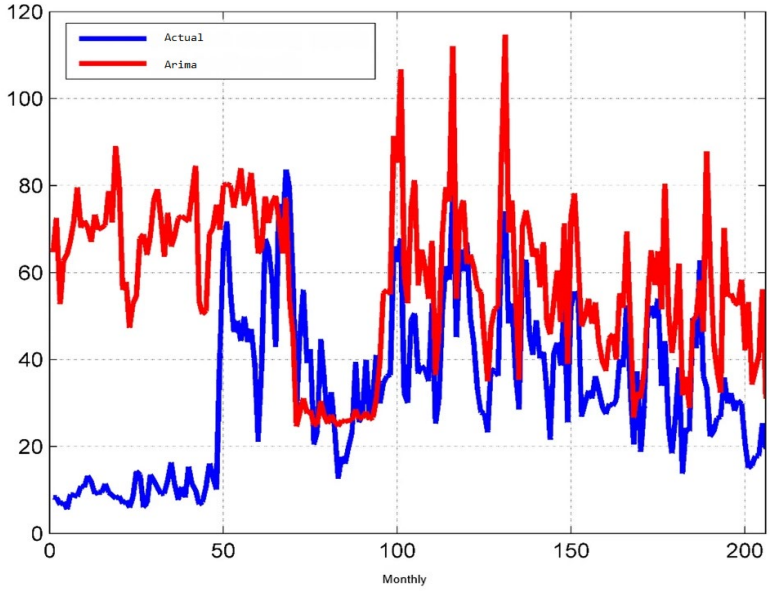

Fig 3: Actual data vs predicted data flow using ARIMA for 2022.

To see the power of ARIMA in predicting the network traffic flow, firstly, the ARIMA analysis of errors between actual and predicted data was conducted on the annual data focusing on an eight-year period, from 2015 to 2022, as presented in Table 2. To clearly determine the ARIMA impact, the same analysis was conducted only for 2022 monthly dataset and is represented in Table 3.

Table 2. Error on Traffic Flow Predictions using ARIMA (from 2015 to 2022).

Exabyte (ZB) Year	Actual data (Dt)	Predictions (Ft)	Errors (Dt-Ft)
2015	47.3	51.1	3.8
2016	51.1	61.1	10
2017	79.3	69.1	10.2
2018	75.3	76.3	1
2019	79.1	82.3	3,2
2020	80.2	84.4	4,2
2021	80	85.1	5,1
2022	84,7	86.4	1,7
MAPE			4.2

Table 2 shows the actual data and prediction data for the ARIMA. The error between the data shows the accuracy of the model. The model in 2015 improved accuracy and performed by 92%. Between 2016 and 2017, the model accuracy decreased between 82% and 87% due to congestion control. From 2018 to 2020, the prediction values were higher than the actual value due to the increase in cloud traffic, and the ARIMA model improved the accuracy to 94% when the traffic increased. In 2022, the accuracy improved to 98%, and traffic accuracy increased to 98% to further investigate the accuracy of the ARIMA model by considering the year that performed better than other years. The study was conducted monthly for the year 2022. To determine this, the same analysis was performed monthly for the year 2022 only.

Table 3: Traffic Flow Data and ARIMA Prediction Data from Jan 2022 to Dec 2022

Observations	Actual Data (Dt)	Prediction (Ft)	Errors (Dt-Ft)
Jan-22	4.3	3.9	0.4
Feb-22	6.7	5.2	1.5
Mar-22	5.9	3.9	2
Apr-22	6.3	4.1	2.2
May-22	4.9	5.8	-0.9
Jun-22	5.7	7	-1.3
Jul-22	7.9	5.3	2.6
Aug-22	8.9	4.2	4.7
Sep-22	6.4	5.2	1,2
Oct-22	5.7	4.9	0.8
Nov-22	6.1	5.9	0.2
Dec-22	7.7	5.2	2.5
MAPE			1.6

Table 3 shows the actual data and the forecast data for the ARIMA. In January 2022, the traffic forecast was 90%, followed by a decline in the forecast the following month (February) to 77%, a further decline in accuracy in March and an incorrect ARIMA forecast to 66%, an April forecast of 65%, an increase in accuracy between May and June when the forecast data was higher than the actual data due to the increase in traffic, a June forecast of 67%, an August forecast of 47%, and an improvement in the forecast accuracy in September to 81%. In October, accuracy increased to 85%; in November, it increased to 96% due to increased traffic; and in December, it decreased to 67%.

In general, the combination of ARIMA and MAPE performs well during high volume of data, of which in this paper, it was provided as a data from 2015 to 2022 (that

comprises combination of daily, monthly, and yearly data sets). However, it performs inadequately during low volume of data (i.e.analysis of individual daily or monthly datasets).

5 Conclusions

In this paper, the SLR was conducted to examine the existing literature to identify the techniques and technologies used to predict traffic flow. The recent techniques used in the literature were identified and categorised. ARIMA was selected to predict the exact expected value of an activity, the traffic flow in cloud computing. A metric, MAPE was used to measure the difference between actual and expected values to indicate how well the model is performing. The results showed that at high volume of traffic flow, ARIMA overestimates the actual values although MAPE quality improves'. The use of cloud computing technology is good for big data. Unfortunately, the traffic flow remains a difficult problem for the network administrator and engineers because of its inability to provide the necessary services to cloud service users.

The combination of ARIMA and MAPE using multivariate time series data is a promising tool for network traffic flow prediction during high volume of data (i.e. annually) but inappropriate in low volume of data (i.e. monthly or daily). In the future, enhancing the availability of the cloud services for allocating resources, the network traffic flow prediction will be conducted using different data analytic tools (i.e. machine learning, computational statistics), These will help to uniquely solve network resource issues at cloud computing organisations and show the best prediction tool that the organisations' could use.

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The Sharing Economy: Understanding South African Graduates' Perceptions Towards Hiring Household Goods Using Online Platforms

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Abstract. Several studies have explored the sharing economy services in areas such as automotive, house-sharing, and bike rentals. The studies predict that sharing economy services will add billions of dollars to the global economy by 2025. As a result, the problem of high unemployment in developing countries may be reduced. Hence, the purpose of this paper is to understand South Africans' perceptions towards the use of online platforms for hiring household goods and to explain the relationships between the factors that influence South Africans' perceptions towards hiring household goods. This qualitative study follows an interpretive philosophy and inductive approach. Fifteen working South Africans were interviewed. The findings provide awareness of how South Africans perceive hiring household goods through online platforms. South Africans are shown to have varying views about whether they can trust online platforms that specialise in hiring out household goods. Furthermore, the study identified the importance of location as a decisive factor and explained that these platforms could enable individuals relocating without the need for owning many household goods.

Keywords: Sharing Economy, Collaborative Consumerism, Hiring Household Goods, Perceptions, South Africa, Unemployment.

1 Introduction

South Africa is a multicultural country with a diverse socio-economic background. It has the world's highest unemployment rate [1] and a high crime rate, with the number of housebreakings increasing from 2.1 million in 2015/2016 to 2.3 million in 2019/2020 [2]. Although South Africa is considered a developing country, it is different to other developing countries in that it has a well-developed infrastructure [3] and it attracts technological companies such as Airbnb and Uber, which offer financial benefits to house and automobile owners [4].

The cultural aspects of South Africans encourage the Botho/Ubuntu philosophy within communities – this philosophy teaches that people are humans through others, and it encourages sharing within communities [5-6]. As a result, the rising concept of the sharing economy (SE) may encourage South Africans to share through digital

technologies. In many conceptions, the SE system is entrenched in efficient-scalable technology that brings large networks of people together and matches them to the goods or services they need [7].

Given that poverty is a social, economic, and political concern in South Africa, the South African government is under pressure to address the legacy of poverty and develop rural areas throughout the country [8]. It is concerning that few SE agencies have emerged in South Africa and that existing businesses are failing to capitalise on the Botho/Ubuntu philosophy. It is also concerning that few SE services have been investigated in South Africa [3]. As such, the study aims to answer the question: How do South Africans perceive the hiring of household goods using online platforms?

This paper will define key terms such as hiring as individuals who acquire temporary access to goods in return pay a fee, hiring out refers to individuals letting someone utilise their goods in exchange for money, and household goods refers to tangible and mobile personal belongings kept in a house unused, such as refrigerators, televisions, gaming consoles and monitors, printers, and toolsets to name a few.

This paper will be divided into the following sections: the literature, the research method, the findings, and the conclusion. It will summarise the related literature as well as discuss and justify the research methodology used to carry out the study. The study will also propose a conceptual model for explaining the relationship between the factors that influence people's perceptions.

2 Literature Review

According to a literature review, researchers are debating the meaning of SE, and it shows that there is no universally agreed-upon definition. As a result, this research will choose an appropriate definition of SE. The literature will touch on key areas that have an impact on the research question.

2.1 Sharing Economy Definition

SE has been around for millennia and is said to be as old as civilisation itself since people have shared their resources with family, friends, and neighbours since they began to live in communities [9]. Nowadays, with the internet growing, various new business models are emerging, making it easier for users to borrow or lend resources to one another via the Internet [10]. It is also important to highlight that the SE comprises a wide variety of activities – peer-to-peer activity, access over ownership activity or digital economic activity; as a result, there are several names for it such as collaborative consumption and peer-to-peer consumption, with no commonly accepted definition fully explaining the SE. SE is described as a peer-to-peer activity that involves gaining, donating, and having access to products and services through community-based online platforms [11]. This, however, runs counter to some of Belk [9]'s ideas which describe SE as people organising the purchase and distribution of a resource for a charge or other rewards, emphasising that for SE to be called "real sharing", no fees or compensations should be paid when sharing activities are per-

formed [9]. It is also defined as digitally connected economic activities which means that a person is considered digitally connected when they have access to the necessary applications, devices, and network infrastructure [12-13].

This study defines SE as collaborative consumerism that aims to create a pleasant living for everyone by promoting the temporary acquisition of goods and services mediated through the internet [9, 14].

2.2 Factors Influencing Participants' Perceptions Towards the SE

Substantial academic research exists exploring factors influencing participants' perception towards SE services [15]. Yet, in the context of developing countries, little research was found. Many well-known theoretical models, such as "tragedy of communities," "prisoners' dilemma game theory" and "logic of collective action" assume that human behaviour is caused by selfish motives [15]. All three theoretical viewpoints contend that it is more advantageous for individuals to engage with one another in many situations. Below are factors that encourage individuals to engage with one another.

Financial Factors. Financial factors are reflected by the current economic crisis, consumer financial constraints, and urban difficulties, SE complements this circumstance since it provides answers rather than a substitute [16]. While the SE appears to result in slower economic development, [17] predict that when sharing costs are reduced while the utility is increased as compared to ownership, the proclivity to select a sharing system will increase over time and financially the benefits of sharing goods add up. Through sharing, people can spread the cost of owning high-quality and durable goods, and people can spread the risk of loss, damage, and depreciation. Suppliers can earn extra income and consumers can get access to luxury items they cannot afford [18] and do not need to pay tax (Value Add Tax) on goods they access through SE platforms [15, 18-19].

Platform Affordance. Platform affordance is when a user adapts and uses innovative technology [20]. This is impacted by factors such as perceived utility and perceived ease of use of the technology.

Social Factors. Social factors relate to people interacting and communicating with one another enhancing the productivity of the SE. Sharing can help everyone get to know the people within their communities and make their communities safer. Friendships could be forged. Individuals participating in the SE service can help one another find resources quicker through referrals. Consumers can save time by checking the reputation of items online [15].

Environmental Factors. Environmental factors follow when people start sharing, they use their underused goods, which reduces manufacturing costs and waste, lead-

ing to a boost in environmental sustainability. According to [16], 76 per cent of consumers feel the SE is positive for the environment since it involves less purchasing, less materialism, and more community building. SE facilitates sustainable consumption, it allows greater access to expensive goods, thereby preserving the environment because the rate of exhaustion of natural resources is reduced [15, 19, 21]. In contrast, environmental factors are not so important for consumers [22].

Factors Reducing Usage and Adoption. Factors reducing usage and adoption indicate that the rapid rise of SE presents both new possibilities and new challenges for public entities [23]. Moreover, SE services challenge traditional businesses and labour unions. They have been called into question in some cases due to violations of the legislation. In 2021, South African Uber drivers were protesting and demanding employment rights [24]. Another issue is linked to trust and safety, consumers of media-sharing platforms might face the issue of downloading or streaming illegal content [9]. There is also a danger of receiving goods damaged [25].

2.3 Summary of Literature

Despite a considerable amount of academic research on the phenomenon of SE, little research has been found on the factors that influence people's perceptions towards hiring household goods through online platforms. The gap in the South African and other developing countries' context is that there is little research found on factors impacting consumer perception towards the platforms that specialise in hiring and hiring out home goods. This study did not adopt any theoretical framework as it could not find an appropriate one.

3 Research Method

This section will focus on the research design, data collection, sample choice and data analysis methods. It gives a general plan of how the research was conducted while stating the assumptions and limitations. The purpose of the research was to explain South Africans' perceptions towards hiring household goods and to explain the relationships between the factors that influence South Africans' perceptions towards hiring household goods. The study adopted an interpretative philosophy to understand participants' lived experiences and viewpoints from their perspectives [26]. These insights and experiences were used to better understand the aspects that influence South Africans' perceptions of hiring household goods through online platforms. Furthermore, interpretivism asserts that each observer has a unique view and interpretation of reality [27]. The approach of the study was inductive because the goal was to search for patterns from data and the development of explanations for those patterns through a series of propositions.

The study used interviews as a data collection instrument because people's opinions were needed to help answer the research question. With that said, 15 informative participants were selected guided by a non-probability sampling technique and the

length of the interviews ranged from 13 to 63 minutes, for a total interview time of 504 minutes. These informative participants were selected because they work in diverse professions that are primarily based in cities and towns. Their roles require them to utilise technology (computers and smartphones) and some scholars also suggest that graduates can be assumed to have access to online services and smartphones [28].

Before data collection, approval was obtained from the university's ethics committee. All participants consented to the research and were free to leave at any time. They were all graduates and were working in various sectors in South Africa. Table 1. Illustrates the demographics of participants.

Table 3. Demographics of Participants.

Participant ID	Highest Qualification	Industry	Role	Years
AD001	BSc. Hon	Telecommunication	Software Developer	8
AD002	BCom. Hon	Financial Services	Software Developer	8
BE003	PG Dip	Auditing	Accountant	3
BE004	BSc. Eng.	Energy	Chief of Engineers	11
BD005	PG Dip	Aviation	Automation Tester	10
AE006	BCom. Hon	Financial Services	Derivatives Manager	9
BD007	N. Dip	Digital Marketing	Graphics Designer	5
AD008	BCom. Hon	E-commerce	Software Developer	7
AD009	BSc	Financial Services	Software Developer	10
AD010	BCom. Hon	Financial Services	Business Analyst	9
AE011	BSc	Financial Services	Head of Risk	9
BE012	BTech	Police Services	HR Partner	14
AE013	BCom. Hon	Financial Services	Head of Finance	11
BE014	BCom. Hon	Auditing	Accountant	3
BE015	BCom	Auditing	Accountant	2

This study adopted inductive thematic analysis because it is the most prevalent type of analysis in qualitative research and the researcher could identify themes and concepts from the data collected and then show how the themes are connected [29]. The data analysis stage required creativity from the researcher as it poses the greatest danger of logical leaps and false assumptions. This means at this stage, there was a likelihood of the researcher making mistakes and needing to apply creative thinking. The researcher used Microsoft Word Online to transcribe face-to-face interviews and Microsoft Teams for online interviews.

To ensure that the tools did not introduce errors, the researcher listened to the interview while reading the transcription. Once the researcher ensured that there were no errors introduced by both tools, the researcher loaded the transcribed files into NVivo for analysis. The researcher took the approach of transcribing one interview at a time and then analysing it before moving to the next interview. This study adhered

to the data engagement steps developed by [30] to ensure data quality. The steps that were followed are:

Step 1 – Familiarise Yourself with the Data. The researcher engaged with the interview recordings by listening to the recordings first before transcribing the data.

Step 2 – Generating Initial Codes. At this step, the researcher is familiar with the data and began coding because the researcher needed to organise the data at a granular level.

Step 3 – Searching for Themes. The researcher examined the codes and collated data extracts to look for potential themes.

Step 4 – Reviewing Themes. At this step, the researcher looked at the coded data to ensure it is placed and fits well within each theme.

Step 5 – Defining and Naming Themes. The researcher created definitions and narrative descriptions of each theme. The researcher provided supporting data to show why the coded data within each theme provides unique insights.

Step 6 – Producing a Report. The researcher worked on a write-up as the final phase and ensure that the report provides a succinct, clear, and logical justification for the selection of the topic**.**

4 Findings and Discussion

This section presents the findings from the data collected and analysed. The study could not find an appropriate framework focusing on hiring household goods services. As such, the research focused on two main parties: the service consumer (borrower) and the service provider (lender), and a conceptual model was developed. To simplify the reading, we will refer to an online platform for hiring household goods as the sharing platform.

4.1 How do South Africans Perceive the Hiring of Household Goods Using Online Platforms?

Perception is the primary cognitive process that a person uses to interact with their surroundings. Because this fundamental aspect of consciousness serves as the basis for or the origin of all conceptual knowledge, the study of perception has always been of particular importance [31]. Even though most participants, especially in major cities of South Africa, were unaware of these sharing platforms, they answered the

inquiries made during the interview process favourably. The data revealed three key impressions. Firstly, the perceived benefit, it is predicted that these sharing platforms will succeed in South Africa. The understanding is that major cities will be favoured more than smaller cities or towns and the service will aid in addressing several issues in South Africa, including the high unemployment rate.

"I do not know but I guess I can see someone taking an advantage of the platform to build a big business for themselves on the platform" (AD010).

Secondly, a substantial number expressed concerns. The assumption made is that the service will not succeed in rural areas, and cultural beliefs in rural areas will hinder the success of shared services. Security was another concern; participants want assurance that security measures will be implemented.

"But in theory based on my experience in townships is that, if you are renting things for too long of a period, people develop a sense of entitlement towards your possessions, even if they are supposed to be paying for them" (AD008)

Lastly, trust perceptions involved building trustworthy connections within their communities and recommending geolocation constraints to be put in place to restrict access to shared resources that are physically close to their neighbours or other community members.

"I would be comfortable hiring from them (neighbours), I think because I have learnt to trust them, or you have learnt to build the relationship with them. So yes, I would." (BE015).

4.2 What Factors Influence South Africans' Perceptions Towards Hiring Household Goods Using Online Platforms?

The factors that affect South Africans' perceptions of hiring household goods are covered in this section. The analysis revealed several factors, some influencing others and are now discussed in detail.

Financial factors. Financial factors include having the possibility of earning extra income which aligns with the literature, which states that suppliers (providers) can increase their profits by sharing their unused goods [18]. Participants are saying having access to these sharing platforms may enable them to generate more revenue: a "Convenient way for people to get some sort of financial benefit from the things they own" (BE003). Participants are excited about the possibility of earning extra income, both the literature and participants' views are aligned, and this factor was significant for this study.

The theme of making better financial decisions. This theme complements the literature which states that consumers can get easy access to luxury goods that they could not afford and will have access to multiple products at a reasonable price [18, 22]. Participants assumed roles when answering the study's interview questions. Most participants expressed that they would participate as both the consumer and supplier (provider). Most out rightly stated that they would be consumers because they do not want to spend money buying items that they will hardly ever use. They echoed that

buying goods that are only going to be used once is a waste. “I think it would be a waste because I would only be using it occasionally, so it is not worth it from my perspective. So, spending like R4000 on something that you use occasionally is a waste.” (BE014). The view of wanting to make a better financial decision is significant for this study because it will positively encourage people to make use of SE services.

The theme of creating jobs and business opportunities. This theme indicates that most respondents believe that these sharing platforms can create both jobs and business. Below is what was echoed by most participants. “I would want to outsource the transportation to other people, like smaller logistic firms. Because that way the value chain moves” (BE003). The study also found contradicting views; some participants think that these platforms will not create jobs but merely create another way of earning an extra income. “I do not believe it would create jobs necessarily. I believe it could create streams of income for the users of the platform” (AD008).

The location benefit factor. The location benefit factor was preferred over the environmental factor. Participants noted that the ability to move from one area to another while having access to goods they need is something that would attract them to hiring household services. “I have moved around quite a few times and sometimes you get to a place, and you do not have a fridge or a microwave, you do not have this or that right? And you also know that you are going to move in the next few months for whatever reasons. So, for such cases, yes, I would hire such items” (BD005). Participants also think that South Africans based in areas closer to affluent areas could use the platform to hire household goods such as gardening tools and create jobs for themselves. These perspectives are significant for this study because they enable some of the perceptions influenced by the financial factor.

Social factors. Social factors refer to the SE promoting a desire to build social bonds within the community. People can create close relationships with their neighbours or form friendships in their local neighbourhoods [22]. Two social themes emerged in this study, outlining the perceived benefits and perceived concerns of using these sharing platforms.

The theme of building a trusting community. This theme involves individuals having the potential to create a strong social bond. Most respondents said they would want to create a solid, dependable community and those with resources will be able to assist others inside their community. “I understand that it creates a society, that assists each other because I also understand that there will be times where I also need something that I do not have but I will also not be willing to go purchase it” (AE011).

The notion of having social problems. This notion alluded to the potential for people to sabotage their relationships if miscommunications occur when sharing things. It is important to remember that these worries are motivated by a desire to feel safe. The study highlights the significance of considering social problems when examining SE. “I think it is better for people that I do not necessarily know because sometimes you know neighbours are going to be there forever and if you have a misunderstanding on

an item that you have lent or they have broken it or something like that and there is no clear indication, even if the company that we are using it can help to resolve that, that relationship breakdown you might not be able to get it again" (BE004)

The two themes are crucial to this study because they connect social, economic, and technological factors. They are significant in that they draw attention to the needs of society and the issues that society is concerned about in their local communities.

Technological affordances. Technological affordances show how a user engages with innovative technology and how they adapt and use it [20]. It also shows how technological advances can enable sharing among community members. In this study, three themes emerged from the data and will now be discussed.

The notion of affording convenience. Affording convenience to consumers indicates that SE has been widely hailed as a major growth sector in various sources. The concept has disrupted matured industries such as automotive and hotels in both developing and developed countries by providing consumers with convenient and cost-effective access to resources without financial and social burdens [21]. In this study, convenience is experienced through technology. Participants are excited that there is a platform that could afford them access to resources they do not have. They expressed their views by stating they this kind of platform will be more convenient for them and will help them save money. They also stated that they will have opportunities to try out products before purchasing them. Example of what was echoed: "It'll be a great platform to experience the product first before going on and getting a long term (Buying goods for the long term)" (BE015). This theme was favoured by the participant and is significant because it demonstrates that consumers in metropolitan areas are looking for a platform that allows them to share their resources. They believe it will improve their lives.

The notion of offering users security. This notion in the study found that participants who were interested in these sharing platforms preferred them to be secure and for users (consumers and providers) to be verified before use. The literature also highlighted the safety screening procedures that Uber uses for their drivers and how it has helped mitigate security concerns [32]. The participants emphasised the importance of having security measures in place for hiring household services, such as geolocation restrictions, to avoid transportation costs exceeding the cost of hiring an item on the platform. Overall, security was an important factor for consumers when considering using these sharing platforms in South Africa. Example of what was echoed: "Yeah, obviously security risks are there, which is why I go back to that point where I said, it is important to have a platform that has people who are vetted or where people can be rated. If you have a low rating and people have feedback on you which can be publicly seen and you can be blacklisted and you know, blocked from the platform completely" (AD010). This theme is significant for this study because it will help potential start-ups or existing SE entities to ensure that they have security measures in place should they wish to explore having their platforms in different regions of the country. It is also worth noting that participants voiced their concerns regarding what shortcomings the platform could have.

The theme of threatening privacy and security. This theme emerged however it had no strong response from participants. Participants are concerned that even though the sharing platform may have security measures, the platform may also introduce other risks. Participants raised concerns such as users creating bogus accounts, possible payment issues and possible identity theft which could lead to not having a safe environment. “Someone has a bogus profile picture, ID number, whatever. And they just ran away with your things that would” (AD008). Privacy and security are two major issues for users of SE services, and clients have difficulty filing claims in local courts [22]. The concerns on technology shortcomings are significant to this study because they will provide start-ups with guidance on what to not overlook and to take some of the lessons that were learned in other SE services.

4.3 How are Factors Influencing South Africans' Perceptions Related to One Another?

The final inductively derived model depicts an overview of the four factors and ten perceptions influencing people's views towards hiring household goods via online platforms (see Fig.1). The model shows the relationships between the factors that are under investigation.

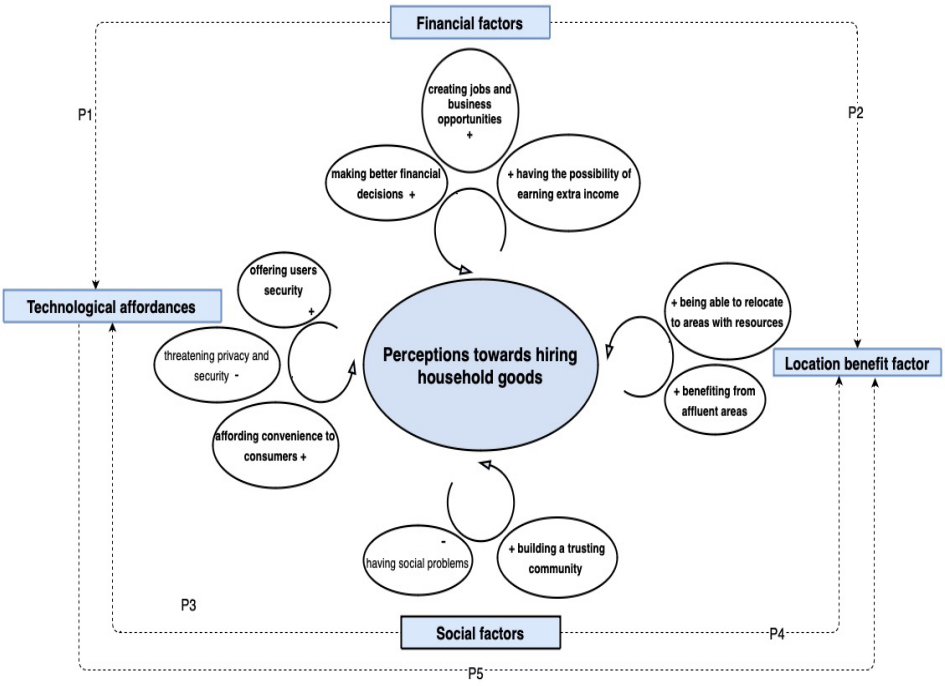

Fig. 4. Explanatory conceptual model of hiring household goods in South Africa.

Because technical traits facilitate economic aspects, economic factors are linked to technological characteristics. Participants predicted that South Africans would have

more opportunities for economic growth, such as the ability to start their businesses or earn more money by hiring services. South Africans will be able to make better financial decisions if they use services. As a result, we propose the proposition: **P1 - Users can benefit financially from hiring platforms**.

Financial and geographical advantages can only be realised in specific regions of the country, implying that sharing platform users will have easier access to items in affluent areas than in rural areas. Participants also claimed that hiring out household goods would not work in rural areas, confirming that sharing platform users would only be able to profit financially in certain areas. As a result of this, we propose **P2 - Users can benefit financially in specific geolocations (especially affluent areas)**.

According to [33], one of the primary responses to the collapse of the social system principle or sense of belonging to a specific social group is the SE. Sharing platforms are thought to have the potential to promote social contacts because they are based on inter-individual social trust. Technological affordances influence social factors in this study. Participants suggested that the sharing platform could assist locals in making reliable connections within their communities. As a result, we propose **P3 - Community members require technology to enable them to share goods securely**.

Location, when combined with social factors, plays a role because participants believe in sharing resources within communities, meaning they would like to build their community by sharing goods among one another. They are concerned about Ubuntu/Botho in affluent areas because they believe the concept does not exist and that sharing goods in such areas is primarily for making extra money. Crime was also a concern, and data shows that crime is prevalent in South African cities. As a result, we propose **P4 – Sharing of goods within a community will be dependent on location**.

Technological affordances play a big role when linked with a location. Sharing platforms include GPS and other geolocational capabilities in both actors' applications (consumer and provider). The platform's purpose is to ensure that users can connect and share within a certain radius of their location [33]. Participants believe that the platform will require geographical constraints so that consumers can benefit from the network's advantages, such as lower transportation costs for commodities moving between locations. As a result, we propose **P5 - Taking advantage of the platform will be dependent on location**.

There is no direct connection between social and financial/economical elements. It is possible to assume that location and technology are the only external elements that can link social and financial gains. For instance, people within a community must be in a specific location and utilise technology to connect to earn extra money or save money. Note that perceptions that arise and received traction in their specific contexts might not be transferrable to other situations [34].

5 Conclusion and Limitations

This study highlighted a gap in research on the factors influencing South Africans' perceptions towards hiring household goods through Internet channels. This gap was

addressed in the study by describing South Africans' perceptions towards hiring household goods, describing the factors that impact South Africans' attitudes toward hiring household goods and explaining how they are interrelated. While many factors were defined in the literature, this study discovered a new factor, location benefit, that influences how South Africans perceive hiring household goods through internet channels. Start-up businesses may utilise this understanding to decide where to apply their offering across all major cities. Based on these findings, newer start-ups can arise by exploiting the existing market. Additional SE services in industries like recruiting may develop. A factor (location benefit) and new perspectives about hiring household goods via online platforms are both introduced to the body of knowledge by the study.

Finally, additional research must be done to comprehend how South Africans view hiring household goods. This study restricted participants to only working graduates and broader perspectives are needed. This study was cross sectional and most participants had not used these sharing platforms. A longitudinal study with users of these platforms would be useful as experiencing and using a platform will impact perceptions. There are also other SE research gaps that need to be addressed, such as maintenance services.

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Organizational Learning Mechanisms Applied in the Adoption and Use of Cloud Computing by Small and Medium Enterprises in South Africa

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Abstract. Cloud computing (CC) is a process and a platform where organizations can access and use a pool of computing resources offered over the Internet. As a digital technology, CC significantly benefits Small and Medium Enterprises (SMEs). SMEs operate in a connected world characterized by a globalized and rapidly changing environment due to evolving Information Systems (IS). In this environment, knowledge becomes a critical resource and basis for competition. Thus, knowledge is critical for adopting and using technology, in this case, CC. Organizational learning is a learning process utilized by organizations. OL is operationalized through OL mechanisms which are used for the facilitation of IS adoption and use. However, limited research addresses OL mechanisms that facilitate CC adoption and use in developing country contexts like South Africa (SA). This study aims to describe OL mechanisms applied by SMEs when adopting and using CC in SA. Qualitative research methods were adopted for the study. The case study method was applied; interviews and participatory observations were used for data collection techniques. Thematic analysis was used for data analysis. Findings revealed that training, exploring CC possibilities; collective learning; experimenting; events learning initiatives; alliances are the main OL mechanisms SMEs apply when adopting and using CC.

Keywords: Organizational Learning, SMEs, Adoption and Use, Cloud Computing

1 Introduction

SMEs are organizations directly linked to improving economies globally [1]. In most developing countries, they account for a significant share of production and employment. In SA, SMEs have become the key instrument for job creation and poverty alleviation [2]; [3]. Like many organizations, SMEs find themselves in a connected world characterized by a globalized and rapidly changing environment due to evolving Information Systems (IS) [4–6]. As a result, SMEs compete globally with large organizations that can adopt and use IS for their competitive advantage [4]. In this environment, knowledge has become a critical resource and a basis for competi-

tive advantage [7, 8]. Thus, knowledge has become a vital resource as the adoption and use of IS requires learning about that particular technology [9, 10], in this case, cloud computing (CC). CC is a platform where organizations can access and share a pool of computing resources over the Internet. The benefits of CC include continuous availability, reliability, and affordability of computing resources. This results in the efficiency of the access and use of computing. This study is focused on SMEs rather than individuals, and it should follow that the adoption and use of CC require OL. Organizational learning is a process of learning in the context of an organization [11]. There are variations of the description of the OL process; however, the general process consists of interpreting, acquiring, distributing, retaining, or memorizing and generating knowledge in the context of an organization [12]. OL is operationalized through OL mechanisms.

OL mechanisms are institutionalized structures and procedural arrangements that aid learning[13, 14]. They may include Research and Development (R&D), training of employees, social learning through electronic media, job rotation, partnering, and traditional classroom learning [15, 16]. OL facilitates the adoption and use of IS in organizations, enabling organizations to develop dynamic capabilities, sustainability, and competitive advantage [17]. The importance of OL for facilitating IS adoption and use is clearly articulated in the literature. However, limited research addresses OL mechanisms that enable CC adoption and use in developing country contexts like SA. Therefore, this study aims to describe the OL mechanisms applied by SMEs when adopting and using CC in the context of SA. The study employs OL as a theoretical lens by viewing SMEs' adoption and use of cloud computing in South Africa from an OL perspective. Understanding the OL mechanism applied in adopting and using CC in the context of SA could advance the successful adoption and use of IS in SMEs in developing countries.

2 Cloud computing

CC is a process and a platform where organizations can share a pool of computing resources or tools offered over the Internet. CC is characterized by five elements: on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service [18] [19]. It allows users to access data resources that are located elsewhere through the Internet. Cloud computing offers several benefits to SMEs. For example, Information technology (IT) resources are accessed via the Internet, implying that service providers are responsible for purchasing relevant tools and maintenance [20–22]. SMEs can access these resources without purchasing hardware equipment, software services and IS skills to maintain systems [23]. In addition, affordability, flexibility and scalability benefit translates to reliable and constantly available resources [24].

2.1 The Benefits of CC for SMEs

Organizations that adopt and use ICT mainly enhance business efficiency and performance [24–26]. This is achieved by integrating ICT with various organizational

functions [27, 28]. Thus, integrating ICT with organizational operations improves the organizations' competitive advantage. While this applies to most organizations, SMEs have faced barriers to adopting and using ICT, such as cost and lack of skilled labour [29]. These barriers were seen as limitations in SMEs' adoption and use [30] of ICT until the introduction of CC [31]. Cloud Computing offers a solution where ICT tools can be accessed and used at a minimal cost [32]. This means that CC allows SMEs to access ICT resources previously accessed by organizations with adequate capital and resources [33]. As a result, CC has allowed SMEs to compete globally and with large organizations [34].

3 Organizational Learning

Organizational learning is a term that has been defined and discussed vastly in the literature [12, 35–41]. The term's definition varies depending on the field of study [15, 42]. However, the consensus is that OL is a set of processes for interpreting, acquiring, distributing, retaining, or memorizing knowledge and generating knowledge in the context of an organization [6, 15, 38, 42–44]. These processes are a means by which Organizational learning is achieved. Organizational learning is operationalized through OL mechanisms [14, 17].

These OL mechanisms manifest and display themselves in various ways [45]. OL can be observed and studied as a phenomenon. A learning organization is unlikely to emerge if these mechanisms do not exist. Generally, learning mechanisms are distributed between external and internal ones. The external ones focus on assisting the organization in exploring learning activities, while the internal ones focus on helping the organization utilize learning activities [45]. These mechanisms include; human resources recruitment; Research and Development (R&D); training of employees; social learning through electronic media; access to open-learning centers; e-learning systems; job rotation; involvement in multi-disciplinary teams; traditional classroom learning, collaborative learning [10], [11, 46], mentoring, alliancing, partnering, license agreements, acquisitions, mergers, seminars [17, 47], performance measurement; audit reviews and problem investigations [48]. The emphasis on the importance of OL mechanisms is that they establish capabilities and know-how in organizations [49]. In addition, these mechanisms secure productivity, competitive advantage, and the ability to sense, interpret, and respond to changes in the internal and external environment [50]. Though this has been established in the literature, it is also important to note that organizations' learning capacity is dependent and influenced by four contextual factors [12, 41].

3.1 Organizational Learning in Information Systems

When analyzing literature in OL and IS, it is evident that the research is distributed into three streams. The first section views IS as a facilitator of OL. In these publications, IS is understood to be an enabler for OL or that it re-enforces OL. Another stream is focused on OL theory and its concepts. In this stream, the literature progresses from OL theory's initial stages to the adaptation of OL theory to further ad-

dress modernized organizations [51]. The last stream of literature views OL as a critical process for achieving positive organizational outcomes [52]. The current study is aligned with the view that OL is a significant process for achieving positive organizational outcomes. For example, in the information age, most work is focused on the importance of OL for adopting and using IS to aid positive organizational outcomes.

3.2 OL is a Process that facilitates the adoption of Information Systems

OL can facilitate a strategic fit and innovation in dynamic environments [46]. It is beneficial for sensing and responding to changes and new business opportunities, particularly in organizations [6, 53]. There are coherent views that OL is necessary for facilitating adequate adoption and the use of IS to achieve positive organizational outcomes [54]. According to [55], OL is essential to IT capability building in organizations. Thus, OL plays a significant mediator between IT competency and organizational performance [6, 56]. The current study's objective is to describe OL mechanisms that SMEs in SA apply when adopting and using CC. Therefore, this study will contribute to understanding OL mechanisms used in facilitating the successful adoption and use of CC in SMEs in SA.

The benefits and significance of adopting and using cloud computing for SMEs have been previously outlined. In addition, they have been supported by various researchers [57–60]. Ultimately, adopting and using cloud computing offers SMEs effectiveness and efficiency, which translates to competitiveness in the fourth industrial revolution [61]. Thus SMEs that have adopted and are using cloud computing in this information age have acquired dynamic capabilities for achieving sustainability and positive organizational outcomes [62, 63].

4 Research Methodology

This study aims to describe OL mechanisms applied in SMEs' adoption and use of CC in SA. Social constructivism was used as an ontological perspective. The social constructivist perspective integrates subjectivism and objectivism [64]. The objectivism perspective suggests that reality exists independently of the human mind [65]. The subjectivity perspective suggests that objects do not contribute to their meaning but that the subject imposes meaning on the object. Separately, these views would not have been ideal in investigating the research question. To this effect, the social constructivist approach would be appropriate in addressing the socio-technical nature of the study.

Interpretivism was adopted as an epistemological perspective [66, 67]. Interpretivism is a way of understanding social constructs to interpret and understand human behaviour [68](Kasi, 2009). The current study is characterized by behavioural science phenomena that are adequately understood through the interpretive approach. The inductive logic was also adopted. This approach begins with observations from the empirical situation and data collected, followed by identifying patterns from observations [69]. The identification of patterns leads to a general theory about the phenomenon. This process aligns with the research objective of identifying and describing OL

mechanisms applied in SMEs' adoption and use of CC in SA. In line with these approaches, qualitative methods were applied to achieve the objective of this study.

The case study method was applied. Participatory observations and unstructured interviews were used as data collection techniques [70, 71]. Participatory observations allowed a deeper understanding of the context and environment of SMEs. The researcher attended meetings, seminars, and workshops. In addition, the researcher engaged in informal conversations with SME employees. Various organizations' cloud computing service providers (CCSPs) organized and hosted these events. The events were helpful in that there were SME representatives that were present. In addition, some events were hosted by organizations that assist entrepreneurs by providing networking opportunities and information regarding funding and Information and Communication Technologies (ICTs).

The events enabled the researcher to engage with SME employees informally. It also allowed for formal engagements like panel discussions and interviews. Also, the researcher was able to attend meetings with CCSP. This allowed for a greater understanding of the external environment of SMEs. The events, interactions and observations were carried out in 24 months. Similarly, unstructured interviews allowed probing in the empirical situation to try and achieve an in-depth understanding. The unit of analysis consisted of 23 SMEs in SA that have adopted and are using CC. The focus was on SMEs in the cities that make up the key economic hubs in SA. They consist of Durban (KwaZulu Natal), Johannesburg (Gauteng) and Cape Town (Western Cape) (NSBC, 2016). The unit of observation consisted of 23 participants comprised of SME owners, executive managers, chief executive officers and chief information officers. In this process of observations, interpretive analysis was adopted by reflecting on the events and interactions with participants [72]. Data emanating from interviews were inductively analyzed using thematic analysis where Atlas.ti was used as a data analysis software tool. [73] The thematic analysis approach was adopted as a systematic six steps process for analyzing data using inductive logic. The process starts with the researcher familiarizing themselves with the data; generating initial codes; searching for themes; reviewing themes; defining and naming themes; and finally reporting on the final themes.

5 Findings

As outlined previously, participatory observations allowed a deeper understanding of the context and the SMEs' environment that use CC in SA. This was significant in that contextual factors influence OL mechanisms. Thus, contextual themes are outlined in this section. In addition, the objective of the study was to describe OL mechanisms used by SMEs in SA for the adoption and use of CC. Therefore, these OL mechanisms are also described in this section.

5.1 Results of Participatory Observations

Contextual themes are significant because the social action and interaction of these SMEs are either affected or caused by their context and environment. This affects the learning processes associated with these SMEs' adoption and use of CC. The context and background that SMEs find themselves in, summarized in figure 1, have implications for SMEs.

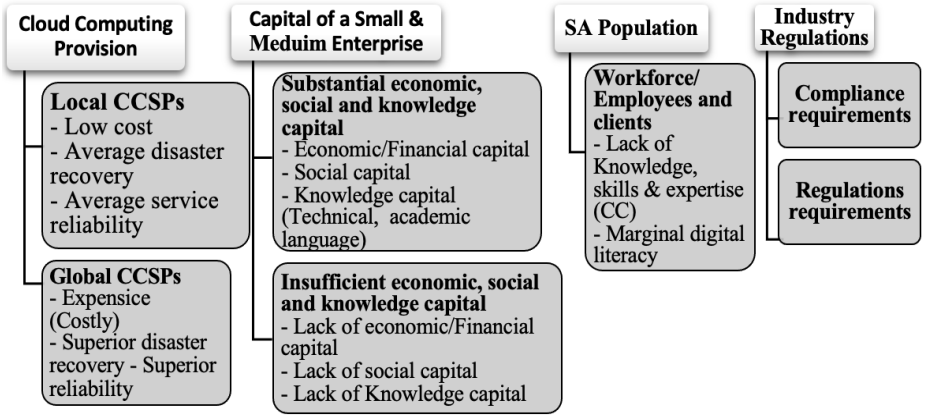

Figure 5: SME Contextual & Environmental Themes

5.2 Contextual Themes and Participatory Observations

Observations showed that CCSPs are made from global and local CCSPs. The global CCSPs have ample resources and expertise in ensuring CC provision to the global market. On the other hand, the local CCSPs have limited resources compared to the global CCSPs. One can liken local CCSPs to the concept of frugal innovations often found in developing countries. The CC technology offered by local CCSPs meets the minimum requirements of a fully-fledged CC technology. The definition and fundamental characteristics of CC technology were established by the National Institute of Standards and Technology {18]. For example, the local CCSP's cloud service would only have a few of those characteristics. This translates to a separation in the type of services that SMEs can access. For example, local CCSPs offer their services at a cheaper rate with minimum offerings. On the other hand, global CCSPs offer their services at an expensive rate with several offerings. The observations and informal conversations show that SMEs that use local CCSPs would have less reliable and available access to CC services. SMEs that use global CCSPs would have improved reliable services. This discovery led to the necessity of understanding the context and type of SME that uses either the global or the local CCSP. SMEs are formally classified according to size (No. of employees) and annual turnover [74]. In addition to this classification, it also became apparent, through observations, that SMEs could also be classified in terms of their economic, social and knowledge capital.

These terms are similar to Bourdieu's concepts of the theory of capital consisting of economic and social capital, including knowledge capital [75]. Economic capital simply refers to the financial capacity of SMEs. Social capital, which includes knowledge capital, refers to relationships SMEs have with key stakeholders in the CC industry and beyond. In this social network, knowledge capital is shared by a broader collective. Numerous stakeholders would meet at important events organized by global CCSPs to discuss and share CC knowledge. Meeting SMEs with less economic, social, and knowledge capital was rare in these events. It appeared as if a group of SMEs were left out of the platforms created for knowledge sharing.

Another observation was the use of language. Representatives from SMEs with capital used technical concepts of CC daily. Representatives from SMEs with less capital who interacted outside this platform used more general and more straightforward descriptions to refer to CC concepts. Another contextual influence is that of industries that SMEs operate in. Various regulations govern industries. Therefore, SMEs need to comply with industry standards and regulations. These standards and regulations affect the adoption and use of CC by all organizations, including SMEs. For example, SMEs with access to personal information about individuals must adhere to the Protection of Personal Information (POPI) Act in SA. This means that the adopted CC service must comply with the POPI Act regulation. Therefore, SMEs need to ensure that the CCSPs adhere to this act. Some SMEs would be unaware of the regulations associated with CC adoption and use. However, in their learning process, they end up reconsidering their operations in the cloud and at times, they may have to migrate to other CCSPs that comply with regulations.

The last important aspect is that of the population. Some SMEs find themselves having to educate and train clients and employees in using cloud services. One cannot assume that the clients are digitally literate and that they can quickly adapt to using CC services. South Africa has a 50% digital literacy rate, one of Africa's highest rates. However, it is still a challenge because 50% of the population is not digitally literate. Therefore, some SMEs find that employees and clients have low digital literacy, which introduces a need to train employees and clients.

5.3 Organizational Learning Mechanism

The OL mechanisms applied by SMEs consist of training, investigative and enquiring activities, collective learning, experimenting, alliances, CCSP's learning initiatives, experience, and documentation (procedures and processes), as shown in Table 1. It consists of themes, subthemes, and the frequency of the subthemes in the data (shown in a numerical value in brackets); lastly, some quotations are associated with the sub-theme.

Table 4. OL Mechanisms Applied by SMEs in the Adoption and Use of CC

Themes	Subthemes	Quotations
Training	Training Employees (47)	*"Once the training is done, you can contact them, you can pay your monthly subscription to have the system up and running, and the*

		integration." R6
	Online videos, tutorials & webinars (8)	*"I just take a look at the webinars on Udemy and I go through the training"* R1
	Training Clients (10)	*"…being first-time users of technology and computers…you give them the basic digital skills and then once they have the confidence…they can engage with online platforms.* R9
	Refresher courses (4)	*"…they have refresher courses…years that we send people on regarding that on any updates"* R3
	Certification (3)	*"But there is a person who is already certified on cloud …."* R1
Investigative and enquiring activities	Research (Journals, blogs, online reviews, search platforms) (41)	*"He made it through by reading the documents, blogposts online…so people will be like this is how we deployed our xyz on AWS in the US. And reading those is like so insightful…"* R8
	Online demos (2)	*"I went to those websites, tried, you know like demos and what-not…"* R17
	Social media (ads) (3)	*"I found it (cloud services) through Facebook…"* R11
Collective learning	Sharing of ideas – formal & informal (42)	*"…they certainly learn from each other… when you put them in a room and they're talking about our ecosystem."* R4
Experimenting	Trial run (29)	*"…I sort of started a bit more experimentation…I played around with google cloud."* R8
Alliances	Partnership (22)	*R23; "…And as we went along, we've then got partners for cloud services."* R9
	Consulting firms (6)	*"We did it in consultation…consultant for certain advice. Basically, that was my own learning…" R10; "You also get a consultant…"* R2
	Helpdesk, support centers, call logs (8)	*"They do have customer support…I think it would have to be like a chat online…they have been helpful."* R5
CCSP's learning initiatives	CCSPs updates (13)	*"…we have a lot to do with Google and we have a team that attend a lot of their conferences."* R2
	Conferences, seminar events (6)	*"…they are always sending us emails about new videos, conferences and to keep you up to date with the advances and new features…"* R13
	CCSPs learning initiatives (6)	*"I think you'll find that a lot of the start-ups… are very spoiled these days because they have Google knocking on their door, AWS knocking on their door."* R4

Experience	Previous Skill and knowledge (22)	*'...I have worked with cloud-based ecologies before, you sign an NDA with service provider." R14.; "...We have all been exposed to the Google cloud platform before."* R16
Documentation (procedures)	CCSPs Documentation (14)	*"...you are always learning new things ...that [CCSPs] documentation is really easy to follow and it's quite easy to find."* R13

6 Discussion

Training is an OL mechanism that most SMEs have used to adopt and use CC. Most SMEs create opportunities for their employees to attend formal training. This includes CCSPs' training, certification offerings for organizations or third parties and refresher (repeat) courses. In addition, the information age comes with training opportunities such as webinars, YouTube videos, and online tutorials. This provides SMEs with options for using training as an OL mechanism. Training is traditionally applied to develop employee competence in various fields. IS organizations turn to send employees for training when an IS has already been adopted [76, 77]. It was interesting to note that a few SMEs offer their employees training before adoption.

One of the respondents explained that "*…you don't want to get trained when you adopt something. You would rather get trained maybe a few months or a few years before as you would know how to support the system, and then you can take over it. Because when you get trained when you are already using the system then you won't be fully qualified to do it but if you do it before, then it will be easy for you*" R1. This was done for the purpose of understanding the strategic fit of CC services for sustainability and organizational goals. OL literature indicates that training is a common OL mechanism used in organizations. However, in the literature, training is not positioned as an OL mechanism that organizations use to test CC suitability for sustainability and organizational goals.

The next OL mechanism is the investigative and enquiring activities SMEs apply in adopting and using CC. This refers to deliberately seeking information through online searches, reading journal magazines, blogs, online reviews, online demonstrations, and social media. The literature outlines these activities [15, 46]. Before adopting CC, SMEs used these activities as OL mechanisms for enquiring about CC. Cloud computing services are generally not advertised; therefore, users have to initiate the process of learning about CC and the possibilities it can offer SMEs. Therefore, SMEs would engage in investigative and enquiring activities about CC.

Another OL mechanism is collective learning. This is where employees learn from each other through sharing and demonstrating ideas. Learning as a collective took place inside and outside the organization through meetups and social activities. This pointed to the OL culture that employees in most SMEs had and the lack of OL culture in some cases. [6] emphasize the importance of a robust OL culture that can enable learning agility in organizations which is vital in dynamic and competitive environments. This OL mechanism is identified as the one that leads to high levels of knowledge acquisition and skills development [78].

Experimenting with CC tools and services has shown to be another way of overcoming the lack of knowledge about CC. Well-known CCSPs have opened their cloud platform for testing and experimenting purposes. The platforms are open at no cost for a given period for both individuals and organizations. This has provided SMEs with opportunities to experiment with CC services before adoption and refine CC competencies during the use (after adoption) of CC. OL literature highlights experimentation as an OL mechanism and its significance. [39], asserted that experiment inspires radical innovation in emerging domains. Experimentation as an OL mechanism has the potential to increase the chances of innovation, this is the goal of OL [11]. It was interesting to note that experimentation with CC services is made available by CCSPs, often at no cost. This may point out that CCSPs may be trying to drive the learning culture and agenda in the CC adoption and use context. This is corroborated using CCSPs learning initiatives that are accessible and available to SMEs. These consist of meticulously organized events for learning processes, from technical lectures and sharing lessons and experiences about business and operational matters. Thus, SMEs would include the attendance of such events as a learning strategy.

Alliances refer to joint ventures or relationships that SMEs have with each other and other organizations that have been essential for learning purposes. Examples include consultants for SMEs, partnerships, and Internet Service Providers (ISPs) that ended up being CCSPs to SMEs. In these relationships, SMEs have leveraged an intangible resource, in this case, knowledge [72]. Various organizations have also used alliances and networks to enhance learning [79]. This OL mechanism is another way of overcoming knowledge barriers well recognized in OL literature. This aligns with the findings, where partnerships with IS service providers become a path for learning about CC, therefore, adopting and using it.

Experience is another OL mechanism that SMEs consider and apply in adopting and using CC. It is also an OL mechanism described and seen as the prime source of productivity. [55] elaborate that IS business experience allows organizations to integrate IT strategy into business strategy. [56] adds that organizations can acquire information through the experience of others. As important as experience is, it is not as prevalent in the data. This may indicate the lack of knowledge and skills of CC. Another OL mechanism that was not prevalent in the data is that of documented procedures. Few SMEs had documented procedures as an OL mechanism. The few SMEs that invested in formalizing processes of using CC services ensured that new employees could quickly learn and follow instructions. In OL theory, documented procedures are memory mechanisms [56]. They serve as a warehouse of information in organizations where they encourage the continuity of CC operations or use optimally. OL mechanisms that have been described are all generally applied by SMEs for adopting and using CC.

7 Conclusion

Organizational learning is significant in SMEs for the effective and successful adoption and use of information systems like cloud computing. Information sys-

tems investment is significantly impacted by an organization's quality of human capital (education). As a practical contribution, SMEs can also implement OL mechanisms identified in the study when initiating and building learning capabilities; and developing human capital in SMEs based in SA. This becomes particularly relevant when considering the rapidly changing environment due to evolving technologies. There is no guarantee that the contextual factors observed and understood about SMEs and the adoption and use of CC in SA are similar to all developing countries. However, the study can be generalizable to developing countries with a similar context as SA. The study employed a different theoretical lens by viewing SMEs' adoption of cloud computing in South Africa from an organizational learning perspective, which is limited in the literature. As a result, the study offers a theoretical contribution to the existing information technology adoption and use theory, adding to the current body of knowledge. Future work can focus on the development of OL theoretical frameworks that can further aid a deeper understanding f the key concepts that enable OL mechanisms.

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A Systematic Literature Review of Online Grocery Retailing Studies: A Research Agenda

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Abstract. Net-enabled organizations have become ubiquitous. However, the emergence of online grocery retailers has not been fully studied. Over the past decades, online grocery retailers have lagged behind other Business-to-Consumer (B2C) e-commerce categories. Moreover, there are limited studies that have been conducted with an in-depth understanding of the nature of online grocery retailing studies. This study provides a systematic literature review of the nature of online grocery retailing based on 83 studies extracted from Scopus, Web of Science, and Google Scholar. The findings show a sharp increase in online grocery retailing studies from 2020 when the COVID-19 lockdown measures were implemented. Most studies are conducted in developed nations with a focus on last-mile delivery, order fulfilment and a suitable online grocery model. This study widens the understanding of the nature of online grocery retailing studies and further identifies research trends and gaps that can be exploited in future studies.

Keywords: E-Commerce, B2C e-commerce, Online grocery retailing

1 Introduction

The Internet has revolutionized how business is conducted and has made e-commerce one of the key catalysts for economic development in many parts of the world [1]. In 2017, B2B e-commerce sales amounted to US$7.7 trillion, whereas B2C e-commerce sales were US$2.3 trillion globally [2,3]. Presently, B2C e-commerce sales amount to US$4.89 trillion and are estimated to reach US$6.39 trillion by 2024, expedited by the COVID-19 pandemic lockdown [4]. Across the globe, B2C e-commerce is experiencing- ing tremendous growth as more people are increasingly favouring buying goods online [2]. Despite these developments, online grocery retailing, which is a category of business-to-consumer (B2C) e-commerce, has yet to receive much attention in the literature, even though grocery products are an essential component of daily life for most people. Most consumers see grocery shopping as a stressful and tedious activity [5,6]. Online grocery retailing could present itself as a potential avenue for making grocery shopping convenient, offering a broader product selection, and saving consumers time and money [7,8]. Studies such as Kühn et al. [9] and Vazqueznoguerol et al. [10] show that online grocery retailers are becoming more popular each day. Dako-

ra and Rambe [48] report how the food and grocery retail sector impressively adopted and implemented digital technologies in South Africa and led to the digital transformation of the sector. Yet, the adoption of online grocery from both retailers and consumers has been slow, particularly in countries with emerging economies such as South Africa [46]. This can partly be attributed to the fact that B2C e-commerce studies are treated as homogeneous without particularizing each type of B2C e-commerce and its significance [2,11]. The adoption of B2C e-commerce varies from one organisation to the other due to the size of the business, the nature of the product or service on offer, and the market conditions under which the business exists [12]. Online grocery retailing, as a type of B2C, is unique due to the perishability and variability of the product and frequency of the shopping activity [56]. Therefore, treating all types of B2C as homogeneous is acting in error and ongoing calls from scholars for an in-depth understanding of online grocery retailing and behaviour are warranted [13,14]. As a first step, this study presents a descriptive view of online grocery retailing with the aim of outlining the current research areas and research methods employed. The rest of this paper is arranged as follows: Section 2 presents related work in online grocery retailing. Section 3 provides the methodology and section 4 the research findings. Section 5 discusses the findings and section 6 concludes the study.

2 Literature Review

Online grocery retailing has many synonyms which are used interchangeably, such as internet grocery retailing [57], electronic grocery retailing [58], e-grocery [19], e-grocer [37], grocery e-commerce [59], and online food retailing [27]. This study defines online grocery retailing as a social-technical system with (people, processes, infrastructure, goals, culture, and technology) that enable the marketing and selling of groceries and other associated services to an end-user consumer over the Internet and deliver groceries to the consumers desired location [13,15,16,17]. Online grocery retailers are divided into two categories. The first is the pure-play grocery retailer, which operates online with no physical store. There are many pure-play grocery retailers emerging across the globe due to the easiness of starting and operating. Other researchers term these types of store stores “piggy bags”, signifying that they pick products for delivery from existing traditional grocery retailers. Their revenue is mainly derived from delivery fees [18,19]. The second category of online grocery retailers is termed multi-channel grocery retailers, which are traditional brick-and-mortar stores that have adopted online channels as a complementary mode of retailing [19,20].

When online grocery retailing term first emerged, they mainly referred to pure plays [21]. However, over the decades, various authors have clustered multi-channel grocery retailers to be another form of online grocery retailer [19,22]. Globally, multi-channel grocery retailers appear to offer a stronger business model as compared to pure-play grocery retailers. In multi-channel grocery retailers, the risk is spread in more than one channel, while in pure-play stores, there is only one channel. How pure-play store stores build competitive advantage is still under study [19].

Studies about online grocery retailing remain limited when compared to other forms of online shopping, which continues to attract huge research interest. Prior studies on online grocery retailing have attempted to understand factors influencing retailers' intention to adopt online grocery. One of these factors is the retailers' beliefs towards online grocery. Kuresh and Thomas [7] posit that outcome beliefs of business expansion, gaining visibility and reputation, customer expectations, inventory management, and margins, costs and technical issues, translate into the retailer's behavioural intention to participate or refuse to participate in the online grocery retailing. The normative belief that the actions and response to online grocery retailing would be governed by their referent group – the consumers, translates into the retailer's behavioural intention to participate or refusing to participate in the online grocery retailing. Finally, Kuresh and Thomas outline that retailer's control belief was that partnering with online grocery retailing would result in loss of control regarding their business operations [7].

Researchers that focus attention on the consumer end of online grocery retailing posit that online grocery shopping relies on the type of personality traits that people have [49]. For example, they conclude that conscientiousness and neuroticism personality traits influence consumers' perceptions of online grocery shopping due to the perceived threats of online grocery shopping. Eriksson and Stenius [50] found that online grocery consumers are within the age gap of 19 to 45 and 'more likely have a higher household size, higher household earnings, and/or they are more likely to live in the capital region of the country' (93). According to Kvalsvik [52], drivers for online grocery shopping among older adults include health, mobility issues, and distance to a store; whilst the younger consumers are driven by the online shopping experience, convenience, relative prices, service quality and food safety [54]. Driediger and Bhatiasevi [63] identify perceived ease of use, perceived usefulness, intention to use, subjective norm, and perceived enjoyment as antecedents for customer acceptance of online grocery shopping in Thailand. To further ensure customer satisfaction and continuance usage of online grocery retailing, Kumar et al. [51] recommend collaboration design as an interactive tool for multi-directional value exchange during the design of online grocery applications. Despite these insights into online grocery retailing, there remains a limited overall market share, with most retailers still lacking a convincing online service and communication strategy [53] and 'questioning the prospects of the maturing distribution channel' [55].

3 Methodology

A systematic review was conducted following the literature search guidelines of the Preferred Reporting Items for Systematic (PRISMA) for identification, screening, and inclusion. This systematic review protocol reduces bias, increases study reliability, and improves the communication of findings [24]. Scopus, Web of Science and Google Scholar were the data sources for peer-reviewed journal articles, book chapters and conference papers. The keywords used in the search protocol include (online grocery retail* OR internet grocery retail* OR electronic grocery retail* OR grocery e-

commerce OR online food retail* OR e-grocer*) in the "Title-Abstract-Keywords" of the above-mentioned databases. Additionally, the search was run on the 28th of August 2022, and all records before this date were identified.

In terms of the eligibility criteria, any peer-reviewed journal article, book chapter or conference paper was considered. All other publications, such as research notes and readers' and editors' comments, were excluded. Moreover, only studies with an online grocery retailer's perspective were considered. This yielded 86 records from Scopus, 109 records from Web of Science and 76 records from Google Scholar. All the records were exported to an Excel spreadsheet, where 158 duplicates were identified and eliminated. While retrieving full-text records, five records could not be accessed as the researchers' institution was not affiliated with the journal publisher. Finally, 108 full-length English articles were obtained, and upon further assessing their eligibility, 25 articles were excluded because they had a consumer study approach instead of an online grocery retailing approach. In total, 83 studies were used in this review. The researcher employed NVivo 12 to manage papers, identify themes and make connections between papers. Each of these papers was analyzed on two grounds: (1) using a thematic analysis approach to identify key research areas; and (2) examining the research methods/techniques used for investigating online grocery retailing.

4 Findings

4.1 Descriptive findings

The findings show that between 2000 to 2015, there was less than a 5% average number of studies conducted with an online grocery retailing focus (see Figure 1). Before the year 2000, there was no study recorded in the databases used. The year 1990 to 2002 represented the dot.com bubble, and most online grocery retailers in the US had to shut down due to fragmented markets and operational inefficiencies [5,25,26]. This might have sparked disinterest in online grocery retailing studies between 2000 to 2015. In 2016, there was a marked increase in the number of studies which continued until 2022.

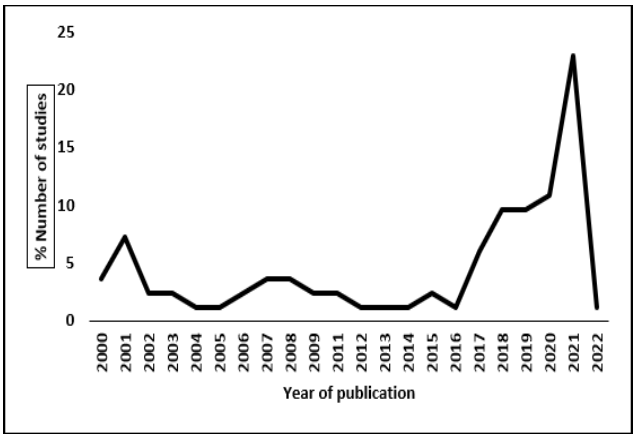

Fig. 1. Number of online grocery retailing studies per year

A sharp increase in studies in 2020-2022 from 10% to 25% is noted. The period of late 2019 onwards was characterized by the COVID-19 pandemic lockdown, limiting the movement of people. It is not surprising to see a rise in online grocery retailing studies in this period, as there was a rise in the need for solutions which include meeting consumers' need for grocery shopping products [27,28]. Moreover, online grocery sales surged during the pandemic [29]. As sales are expected to continue to rise [29], it is expected to see a continued increase in online grocery retailing studies.

According to Figure 2, 71% of the online grocery retailing studies were conducted in developed nations, with US, UK and Spain constituting 14%, 13% and 10% of research studies, respectively. In contrast, developing nations' studies were 12%. Among them, South Africa had 4%, followed by India with 2%, and the rest of other developing countries had 1% of studies. There is a gap in the literature for more studies from a developing nations' perspective. About 17% of studies such as [30,31] were not linked to any country as most researchers chose to conduct simulations and computational modelling.

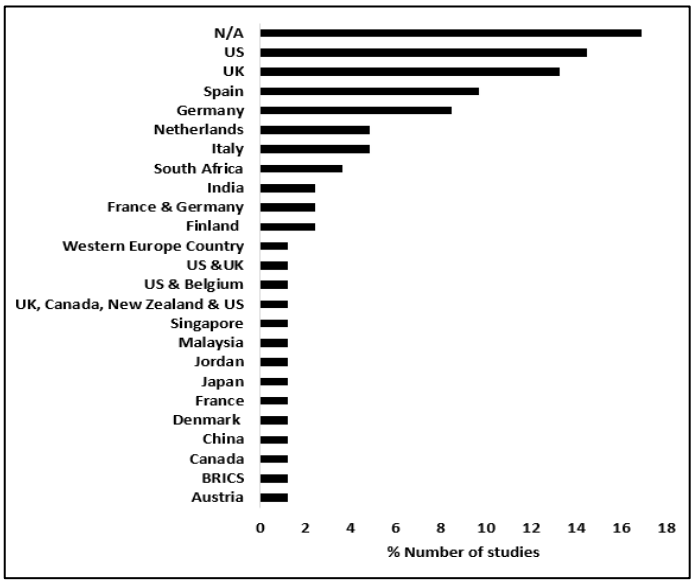

Fig. 2. Number of online grocery retailing studies per country

4.2 Emergent themes in online grocery studies

The top three themes that emerged in the online grocery retailing studies are last-mile delivery, order fulfilment, and online grocery retailing model (see Figure 3). Studies with a last-mile delivery (28%) focus constitute the largest share of online grocery retailing studies. Generally, last-mile delivery is a complex activity within the e-commerce industry [32]. Weber-Snyman and Badenhorst–Weiss [65] detail four specific last-mile logistical challenges for emerging economies faced by retailers. They include reliable order fulfilment, cold distribution chain requirements, forward logistical challenges and reverse logistics in online grocery retailing. In Kenya, last-mile challenges include 'the lack of a good national addressing system, traffic concerns, security concerns, high cost of delivery, postal service unreliability, and unconducive county government by-laws' (387) [67]. In general, the efficiency of the last-mile delivery determines the delivery costs and customer satisfaction [33,34]. Distributing goods from the warehouse to the desired customer location is costly, and the current delivery models are not sustainable as the costs far exceed the income [23,32,35]. Previous studies recommend using computational models to improve on-time delivery performance [35,36,37]. Additionally, the effectiveness of the last-mile deliveries should be considered in conjunction with the environmental impact due to carbon intensity [23,35]. The convenience offered by online grocery retailers has social, environmental, and economic costs in the form of increased carbon emissions, higher prices, and additional congestion on the roads [35]. Online grocery retailers need to look holistically at the entire order fulfilment to be able to decide on suitable last-mile delivery options.

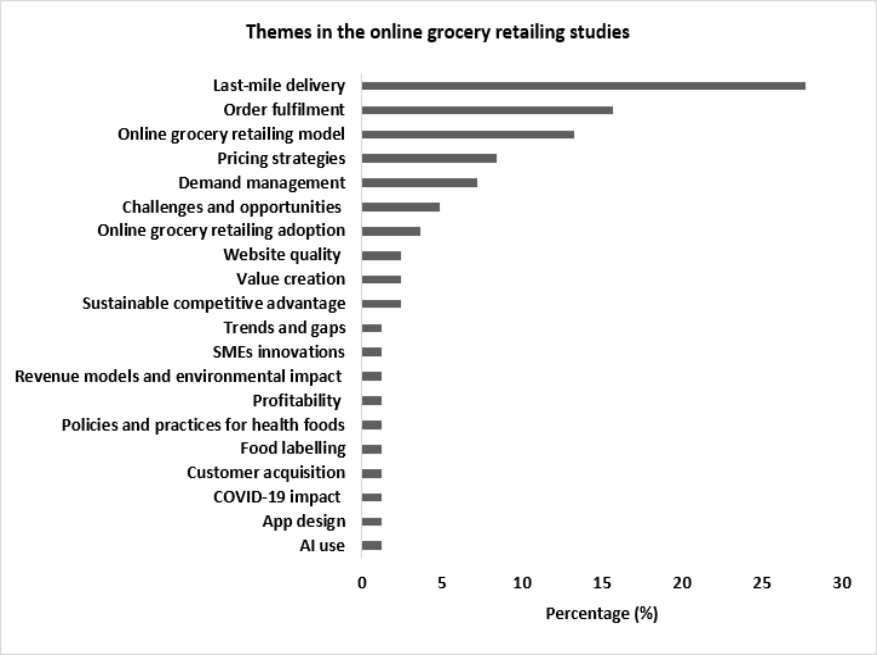

Fig. 3. Themes in the online grocery retailing studies

The next theme receiving closer attention is order fulfilment with 16%. Order fulfilment is an important function in online grocery retailing. It entails the process of sourcing, receiving, warehousing, packaging, and delivering customers' orders. Unlike non-perishable items, the nature of most grocery merchandise makes the distribution complex. Grocery products are characterized by high levels of perishability and fragility [22]. Moreover, designing cost-efficient order fulfilment models is challenging for online grocery retailers across the globe. Many obstacles must be overcome until a large-scale fulfilment model exists among grocery retailers [19,23].

The theme of online grocery retailing model was also frequently noted. Studies in this category sought to look at online grocery retailers holistically to determine the viable model [38,39]. Related studies examined the challenges and opportunities of online grocery retailing [40,41]. Like any other business model, online grocery retailers are not immune to challenges. The nature of online grocery retailers' challenges mostly emanates from the nature of the products they sell. Mainly, grocery products consist of fresh, frozen, and perishable products, making them difficult to store and transport [10,21]. These require the customer to be home, limiting last-mile delivery options [10,33]. Researchers in these studies are concerned with looking for opportunities to exploit to maximize the potential of online grocery retailers.

4.3 Research Methods employed in online grocery studies

The findings show that 59% of the studies employed quantitative studies, while 41% used qualitative research methods to study the online grocery retailing phenomenon. The quantitative studies employed mainly mathematical modelling, especially in developing efficient delivery methods [31,33]. The qualitative studies surveyed mostly used semi-structured interviews supplemented by secondary data [7,27,41]. Some qualitative studies took a case-study approach [42,43].

In terms of the eligibility criteria, any peer-reviewed journal article, book chapter or conference paper was considered. All other publications, such as research notes and readers' and editors' comments, were excluded. Moreover, only studies with an online grocery retailer's perspective were considered. This yielded 86 records from Scopus, 109 records from Web of Science and 76 records from Google Scholar. All the records were exported to an Excel spreadsheet, where 158 duplicates were identified and eliminated. While retrieving full-text records, five records could not be accessed as the re- searchers' institution was not affiliated with the journal publisher. Finally, 108 full-length English articles were obtained, and upon further assessing their eligibility, 25 articles were excluded because they had a consumer study approach instead of an online grocery retailing approach. In total, 83 studies were used in this review. The researcher employed NVivo 12 to manage papers, identify themes and make connections between papers. Each of these papers was analyzed on two grounds: (1) using a thematic analysis approach to identify key research areas, and (2) examining the research methods/techniques used for investigating online grocery retailing.

5 Discussion

The findings in this study show that studies on online grocery retailing are only starting to become prominent in recent years. More specifically, a gradual increase starting in 2016, followed by a sharp increase in 2020. The recent rise in online grocery retailing studies can be attributed to the COVID-19 global lockdown regulations, which limited the movement of people, and retailers started looking for alternative ways to sell groceries to consumers [27,28]. Online grocery retailing has become an alternative, and this trend is expected to continue [23]. The findings of Tyrväinen and Karjaluoto [60] were interesting as they show that COVID-19 decreased the importance of the perceived usefulness of and attitudes toward online grocery purchase intentions. These findings seem to contradict prior results that perceived usefulness and attitude have the strongest effect on consumers' attitudes toward online grocery shopping [61,62]. This observation calls for more investigation into the contextual predictors of online grocery retailing and continuous customer purchase intentions.

Further findings in this study show that most online grocery retailing studies are conducted in developed nations. Developing nations combined have about 12% of studies conducted on online grocery retailing. There is a vast gap in the literature for more studies with an online grocery retailing perspective in developing nations. Several studies allude to the growth potential for online grocery retailing in developing na-

tions [7,19,44]. Moreover, studies with developed nations focus cannot be generalized to developing nations due to differences in grocery market growth, infrastructure development, socio-economic growth, and internet penetration [44,45,46]. According to Lambrechts et al. [68] 'developed countries are not always aware of the additional issues such as affordability of broadband internet, and a lack of infrastructure to distribute the internet that are dealt with in emerging markets on a daily basis, albeit these challenges might also exist to a lesser extent, in some form or another, in the developed world. Furthermore, the results show most studies are quantitative in nature. To have a contextual understanding of online grocery retailing, and provide context-specific solutions, there is a need for more qualitative studies from the developing nations' per- perspective.

Areas that are given attention in the literature regarding online grocery retailing are last-mile delivery (28%), order fulfilment (16%) and online grocery retailing model (13%). Within online grocery retailing operations, last-mile delivery and order fulfilment play a significant role in the profitability of the business. To address challenges associated with last-mile delivery, Devari et al. [64] propose using friends in a social network to reduce delivery costs and total environmental emissions while ensuring speedy and reliable delivery. Such a proposition is now featured more frequently under the umbrella of Crowd Logistics Delivery (CLD), which is becoming the most innovative solution for online shopping to avoid last-mile challenges [66]. Additional solutions for areas with a lack of a good national addressing system include retailers requesting their customers to share location details via online map applications such as Google Maps [67]. However, there is a need for more studies that critically examine various operational areas of the online grocery retailing business that are also key to the organization's success. For example, studies about sustainable competitive advantage receive limited attention and yet most organizations in developing countries find it difficult to sustain their operations within their first five years of existence [47]. These findings call for more studies in the online grocery retailing area to understand how other factors (themes), such as sustainable competitive advantage, revenue models and value creation, can enable the success of online grocery retailing in developing countries.

6 Conclusion

The purpose of this study was to present a descriptive view of online grocery retailing with the aim of outlining the current research themes and research methods employed. The study followed the PRISMA approach and identified three key areas of research in online grocery retailing. These include last-mile delivery, order fulfilment and online grocery retailing model. The study notes that the areas that do not receive attention in literature have dire consequences for the growth and sustainability of online grocery retailers. This is a challenge for developing countries because with the developments in digital technologies and services, as well as the customer push for convenience, especially after the COVID-19 pandemic, there will be an increase in online grocery services in the future. Therefore, understanding the role of the other thematic

areas in ensuring the growth and sustainability of the business is important, given that the current understanding of online grocery retailing tends to come from the developed economies and a more context-specific viewpoint from the developing countries is absent. Additionally, researchers tend to pursue quantitative research, especially using computational modelling. However, qualitative studies are better at enabling one to gain a richer and deeper understanding of online grocery retailing. Future studies can consider using qualitative inquiry in the examination of online grocery retailing.

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The Lack of Education Development in the Global South Caused by Data Access Limitations: A Thematic Analysis

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Abstract. Digitalization within the education sector is becoming an increasing trend, especially since the onset of the COVID-19 pandemic. Many countries have adopted E-learning technologies to keep up with current trends. However, low-income and middle-income countries need more capital, infrastructure, technical skills, and access to data to adopt this change. This article highlights the need for more education development in the Global South due to data access limitations. A thematic analysis has been conducted to identify the current state of the education sector within the Global South and the Global North and the current state of access to data within the Global South and the Global North. The data was then used to highlight the differences and disparities between these regions regarding the education sector and how data access can positively change regions within the Global South. This article contributes to the existing body of knowledge and research surrounding the Global South, its digitalization efforts, and education development or lack thereof.

Keywords: Global South, Data Access Limitations, Digital Development, Education Disparity.

1 Introduction

In the current era of digitalization, having access to data is no longer a luxury but a necessity. Data availability and access has brought about significant changes and opportunities for economies worldwide. Access to data not only plays a crucial role in digital development but also in the development of education [1]. Developed countries have taken advantage of data and its appropriate use, being digitally connected since the 1990s [1]. On the other hand, the Global South, which includes less economically developed countries in Africa, Asia, Latin America, and Oceania, lags behind due to their limited access to data and infrastructure. These countries face the challenge of inadequate regulations and frameworks surrounding digitalization, which can have severe implications for their citizens and countries [1, 2].

The Digital Age has presented numerous opportunities and challenges throughout this century. Developing countries require more resources, infrastructure, legal requirements, capital, and skills to keep up with the rapid pace of digitalization. While Foreign Direct Investment (FDI) can help mitigate these issues, it also has drawbacks,

such as unsustainable resource utilization and surface-level digitalization [3]. Additionally, these developing countries lack regulations and the capacity for large-scale domestic and data processing and usage, which must be addressed for them to fully benefit from digital development. Therefore, there is a need for digital development initiatives that apply technological tools to contribute to a country's economic and social growth [1].

This article focuses on the issue of educational disparities in the Global South resulting from limited access to data. It sheds light on the differences between education development in the Global South and Global North and the challenges developing countries face in achieving effective education development due to government policies that often need to be more effective and efficient. External education development projects and initiatives are also met with resistance due to political conflicts between governments and citizens. This leads to students falling behind in their education, particularly during times of conflict and war [4]. Such disparities between the Global South and Global North in education development highlight the need for access to data. The main research question is: To what extent do data access limitations contribute to education disparities in the Global South? The objectives of this article are to highlight the differences between the Global South and Global North in data access, digitalization, and education development and to explore the potential of data access to promote educational development in the Global South. The goal is to sensitize the reader to the gap between the Global North and South in terms of data access.

2 Background

The term 'Global South' originated in the 1990s, after the Cold War [5]. Although it may be used interchangeably with 'third-world', there are some differences between the two. The term 'Global South' goes beyond a mere geographical distinction, as it also includes regions in the North that have suffered from imperialism, colonialism, and exploitation. This means that it includes all developing regions that have been subject to colonialism rather than being limited to specific geographical regions [6].

The emergence of new technological opportunities and innovations tends to primarily benefit the Global North and large corporations, as these opportunities are centered on wealthy and developed countries [7]. Although media outlets frequently report on digitalization processes in the Global South, the reality is that many countries in this region continue to face issues such as the digital divide and economic inequality [8].

Many large corporations have set up technology hubs in African countries, contributing to these regions' foreign investment and digital development. This has led to an increase in the provision of digital services in recent years. However, while international governments can provide some support, national governments have a crucial role to play in driving digital development. While progress has been made in recent years, many of these governments must clearly outline their long-term goals and strategies to achieve them. Moreover, some governments in these regions have been

known to abuse their political power by manipulating and restricting the flow of information, particularly during significant political events [8].

The COVID-19 pandemic has exposed the inadequacies in the digital policies of numerous countries and brought to light the severity of the digital divide. As lockdown measures were implemented to curb the spread of the virus, the education sector had to shift to e-learning platforms. This amplified the differences in digital access, economic status, education, and social well-being as many individuals lacked the required resources to make the transition [9]. Several of these students, particularly in rural regions, are still facing challenges as they have not been given adequate support to catch up with their counterparts who have successfully adapted to the new digital landscape.

The lack of education development and reform in developing countries has led to a "global learning crisis," according to the United Nations Children's Fund (UNICEF) in 2020 [10]. Children in these countries are not receiving adequate education due to poor learning conditions, ineffective teaching methods, gender bias, and other factors. This results in a high illiteracy rate among children, particularly girls, leading to increased unemployment rates and hindered economic and political development due to a lack of resources and effective policies [11]. Therefore, it is essential to have access to data to promote digital development and economic equality. Generating solutions for these issues is crucial as current and future economies continue to suffer from past and present inequalities.

3 Research Method

This study utilizes a systematic literature review approach to investigate education disparities in the Global South caused by data access limitations. The methodology adopted follows the steps recommended by Cruz-Benito [12], including identifying relevant sources from scientific databases, filtering results based on inclusion and exclusion criteria, assessing the quality of the results, and extracting pertinent information that is most useful for the research. After the conclusion of the systematic literature review, the thematic analysis is done.

3.1 Data Sources and Search Terms

Data Sources: The data sources utilized for this study include well-known academic databases, such as JSTOR, ProQuest, EBSCOhost, SAGE Journals, and the search engine Google Scholar. These sources were chosen due to their reputation for providing credible and relevant publications related to the chosen topic. Although Google Scholar is not an academic database, it was also included as it contains relevant publications related to the research topic.

Search Terms: In the JSTOR, ProQuest, EBSCOhost, and SAGE Journals databases, as well as the Google Scholar search engine, the following string with multiple search terms was utilized:

("Education development") AND ("Global South" OR "Developing countries" OR "Third-World") AND ("Global North" OR "Developed countries" OR "First-World") AND ("Data access" OR "Digital development")

3.2 Selection Criteria

The following sub-sections discuss the inclusion and exclusion criteria that was included when searching for and including publications relevant to this research topic.

Inclusion Criteria: The following is a list of the types of sources which were included when conducting research:

7. Books, web articles, journal articles, periodicals, and research reports.
8. Blog entries and websites for general information and definitions only.
9. Publications in English.
10. Publications relevant to educational development in the Global South.
11. Publications relevant to data access in the Global South.
12. Publications up until 2022.

Exclusion Criteria: The following is a list of the types of sources which were excluded when conducting research:

13. Publications not written in English and that do not offer any English translation.
14. Duplicate papers.
15. Publications where only the abstract is available but not the full text.
16. Publications not relevant to the research topic.

3.3 Prisma Flowchart

The following diagram depicts the source selection process and the number of publications included in the final research. Publications that were excluded or left out are duplicates and publications that did not meet the specified inclusion criteria:

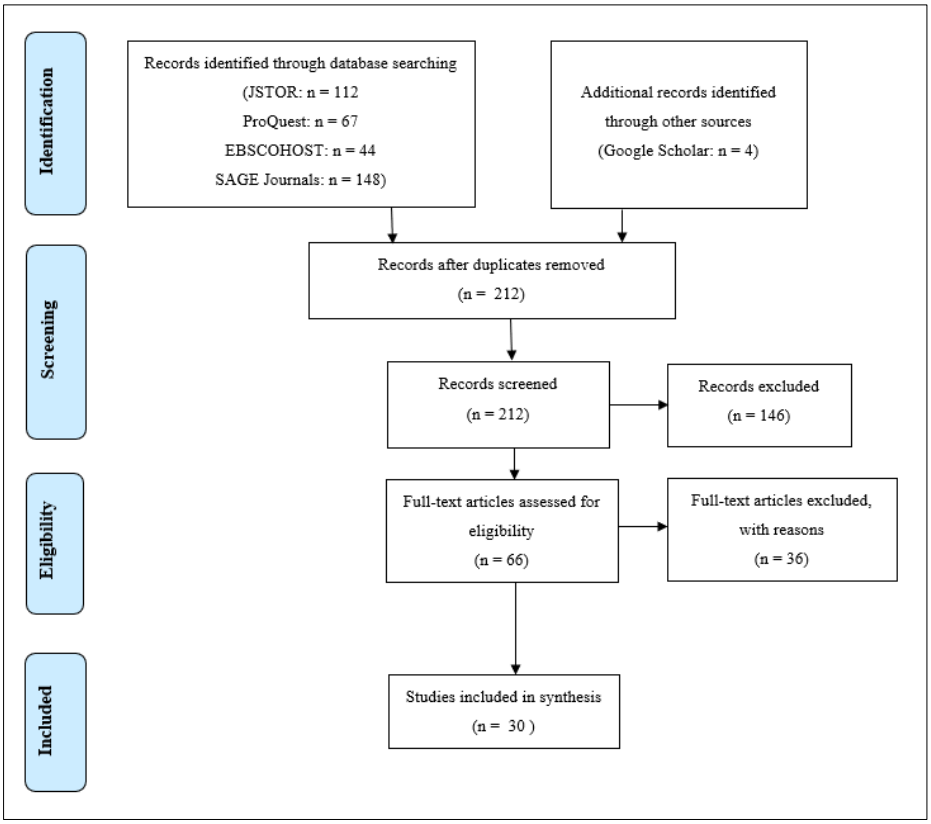

Fig. 6. Prisma Flowchart.

3.4 Quality Assessment

Publications included in this study have additionally been evaluated using quality assessment criteria. Each publication being used in this systematic literature review will be assessed via a set of quality assessment questions, and each question will be applied to each publication and will be given a score of "1", which indicates that the publication meets all the requirements of the question being asked, or "0.5", which indicates that the publication partially meets the requirements of the question being asked, or "0", which indicates that the publication does not meet the requirements of the question being asked. Four QA (Quality Assessment) questions have been used when analyzing each publication. The quality assessment criteria are as follows:

QA1: Does the publication contain information regarding data access in the Global South?

- Y (Yes) (1): The publication contains information specifically on data access in the Global South.

- P (Partially) (0.5): The publication contains some information on data access in the Global South.
- N (No) (0): The publication does not contain any information on data access in the Global South.

QA2: Does the publication contain information regarding education or education development in the Global South?

- Y (Yes) (1): The publication contains information specifically on education or education development in the Global South.
- P (Partially) (0.5): The publication contains some information on education or education development in the Global South.
- N (No) (0): The publication does not contain any information on education or education development in the Global South.

QA3: Does the publication contain relevant information regarding data access differences between the Global South and the Global North?

- Y (Yes) (1): The publication contains information specifically on the data access differences between the Global South and the Global North.
- P (Partially) (0.5): The publication contains some information on the data access differences between the Global South and the Global North.
- N (No) (0): The publication does not contain any information regarding data access differences between the Global South and the Global North.

QA4: Does the publication contain relevant information about the digital divide between first-world, third-world, and/or developing countries?

- Y (Yes) (1): The publication contains information specifically on the digital divide between first-world, third-world, and/or developing countries.
- P (Partially) (0.5): The publication contains some information on the digital divide between first-world, third-world, and/or developing countries.
- N (No) (0): The publication does not contain any information regarding the digital divide between first-world, third-world, and/or developing countries.
  The results showed that 70% of the publications included in this systematic literature review met or exceeded the median score. The remaining 30% of publications fell below the median score as they did not meet most criteria. However, they still contain information relevant to this study, hence their inclusion.

3.5 Data Extraction

Data has been extracted from various renowned and reliable journals and databases. The data extracted consists of analytical, descriptive, interpretive, and qualitative data and can be generalized as a qualitative synthesis. The extracted data includes relevant information from each publication to this study, such as data on the Global South, Global North, digitalization, digital divide, data access, and any other information of relevance. Please refer to Appendix 1 for the Data Extraction Table.

3.6 Data Analysis

The data analysis method used in this study is a thematic analysis. This qualitative method identifies, analyzes, and determines data patterns within qualitative data sets. According to Maguire & Delahunt [13], the thematic analysis method uses the following steps:

- Gain an understanding of the data.
- Develop coding systems to categorize the data.
- Recognize patterns or themes within the data.
- Assess the identified themes.
- Provide descriptions for the identified themes.
- Present a comprehensive report on the themes.

4 Findings

The findings are summarized below:

- According to the data, 27% of the thirty publications included in this research were sourced from JSTOR, while 33% were sourced from Google Scholar. SAGE Journals had the highest contribution, accounting for 40% of the publications.
- The majority of the thirty publications used in this research fell within the 3 to 4 criterion range, indicating that they provided valuable information that addressed most, if not all, of the quality assessment questions in this systematic literature review. Even publications scoring below 3 were included as they still offered useful insights that contributed to the foundation of this review.
- The publications used in this systematic literature review were predominantly published between 2016 and 2020. This period saw an increase in the number of publications, likely due to the growing integration of technology in academic institutions and the shift from traditional classroom approaches to online learning methods triggered by the onset of the COVID-19 pandemic in 2020.
- As per the data, 6% of the thirty publications used in this systematic literature review were extracted from books, while 17% were obtained from research reports. Journal articles made the highest contribution at 77%. This is because journal articles provided extensive research on the background, technological advancements, and educational state of the Global South, while the reports utilized in this research offered numerical data on technology and educational access in Global South countries.
- Out of the thirty publications included in this systematic literature review, the majority employed an analytical research strategy. It is worth noting that some publications utilized a combination of two research strategies. Analytical publications were predominantly chosen because they already presented available facts and information from previous studies. The following diagram illustrates the main themes explored in this systematic literature review, with each main theme further broken down into sub-themes discussed throughout the paper.

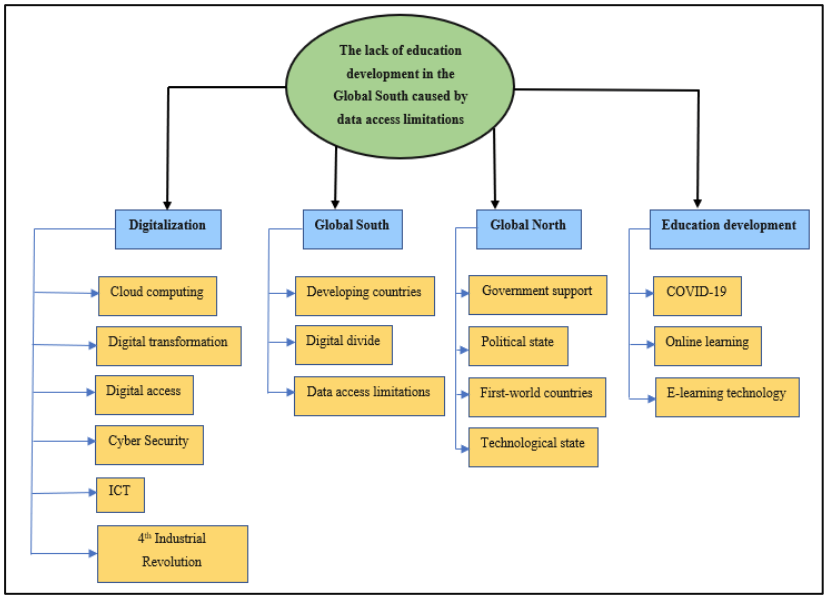

Fig. 7. Fig. 8. Results of Thematic Analysis.

During the analysis of publications covering the theme of digitalization, it was observed that these publications explored various aspects such as cloud computing, digital access, cyber security, and more. Publications focusing on the Global South often delved into topics like the digital divide and limitations in data access within these regions. The term "Global South" was frequently used interchangeably with "developing countries." Furthermore, publications that discussed the Global North in relation to the Global South highlighted the political and technological disparities between these regions. The term "Global North" was commonly used synonymously with "first-world countries." In publications concerning education development, many addressed the recent advancements within the education sector influenced by the COVID-19 pandemic. The digitalization of education and the utilization of e-learning technologies emerged as common themes in publications related to education development utilized in this research.

The subsequent section builds upon the aforementioned themes and sub-themes to further explore and provide insights in response to the research question.

5 Discussion

5.1 The Current State of the Education Sector in the Global South

More than half of primary and lower secondary school age children globally are not achieving the minimum proficiency levels in mathematics and reading, as reported by

Ferguson and Roofe in 2020 [14]. The majority of these children are from developing countries in the Global South, particularly those in low-income nations. Many of these children are unable to read or perform basic mathematics due to the lack of access to quality education. This can be attributed to various factors such as the inability to afford education, a lack of schools in rural areas, insufficient number of teachers, homelessness, or the need to work to support their families. These factors have resulted in about 40% of adolescents worldwide not attending or dropping out of school with a low chance of re-enrolling or entering school [10].

5.2 The Current Statistics on Out-Of-School Primary-Aged Children Worldwide

According to Roser [15], UNESCO reported in 2019 that 58.4 million primary school-aged children worldwide, which equates to 8% of the total number of primary school-aged children, do not attend school. Figure 3 below presents a comparison between the number of primary school-aged children not attending school in the Global South and the number of those not attending school in the Global North. Figure 3 displays the distribution of primary school-aged children who are not attending school across different regions:

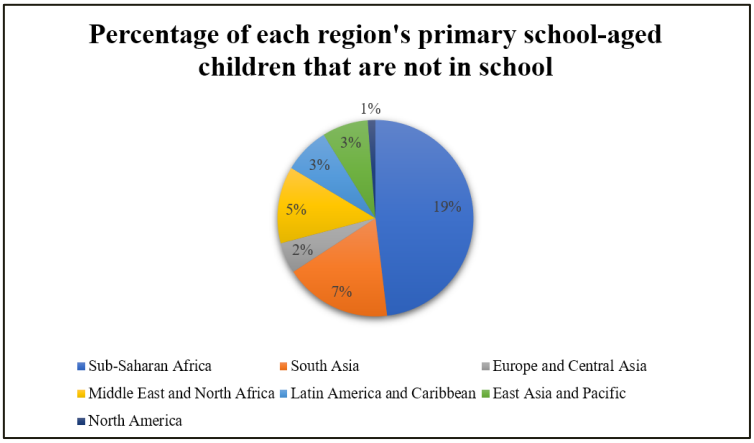

Fig. 9. Percentage of each region's primary school-aged children that are not in school [14].

As can be seen in figure 3, Sub-Saharan Africa has the highest percentage of children, with 19%, who are not receiving an education. In South Asia, 7% of children are not in school, while in the Middle East and North Africa, the figure stands at 5%. In Latin America and the Caribbean, East Asia and the Pacific, Europe and Central Asia, and North America, 3%, 3%, 2%, and 1% of children, respectively, are not attending school. A significant contrast between more affluent regions, such as North America, and financially disadvantaged regions, such as South Asia, can be observed.

According to a 2020 report by UNESCO, there were 244 million school-aged children and adolescents globally who were not attending school [16]. This is a decrease

from the 401 million out-of-school children recorded in 2000. However, the percentage of children in Sub-Saharan Africa who are not attending school has increased. In 2000, Sub-Saharan Africa accounted for 31% of the total percentage of primary school-aged children not in school worldwide. By 2021, this had risen to 55%, as reported by Antoninis and Montoya [17]. Figure 4 depicts the percentage of primary school-aged children not attending school by region as of 2021.

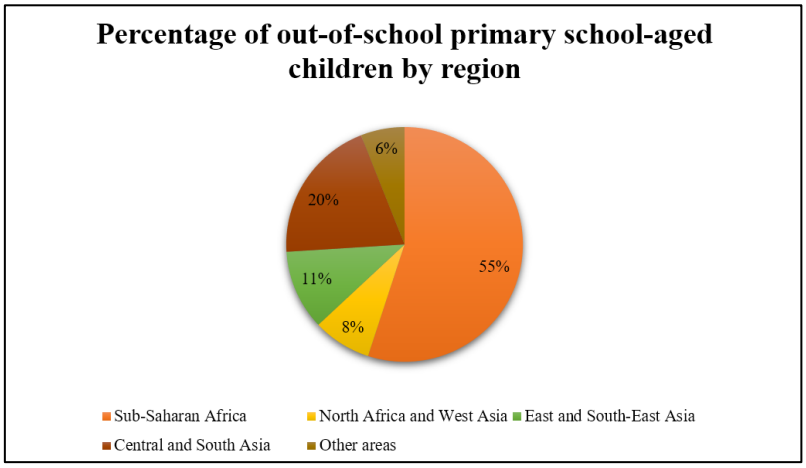

Fig. 10. Percentage of out-of-school primary school-aged children by region [16].

The pie chart shown above demonstrates that 55% of the 244 million children globally who are not in school belong to Sub-Saharan Africa. There are several potential reasons for this, including the region's high population, limited access to data and technology, economic status, poverty, insufficient skills and training, among other factors.

5.3 The Current Status of Data Access in the Global South

Limited data access is a challenge in the Global South, which is attributed to various factors such as the lack of digital skills, affordability, and internet accessibility. The digital divide reflects inequalities in society, including social and economic disparities. In low and middle-income countries, less than half of the population has internet access, and many individuals cannot afford data due to low average monthly salaries. Furthermore, there are limited alternatives to the current data plan models that are affordable for many people in Africa, as discussed by Bastion and Mukku [1].

A lack of access to electricity in underdeveloped countries is another hindrance to data access, preventing individuals from accessing the Internet and other digital services. In areas with established cellular towers where people can afford data, the towers can only function for a few days without electricity. If power outages are frequent or prolonged, the cellular towers become inoperable. A further constraint is the limited availability of internet content as 56% of the content is exclusively accessible in

English. This presents an obstacle to utilizing the internet for educational purposes in nations where English is not the primary language [1].

Additional limitations include inadequate technical skills and insufficient funding to build necessary infrastructure. Governments may also face challenges in establishing frameworks and policies that safeguard individuals' private and personal data from being compromised or misused. Furthermore, research indicates that many governments lack the expertise to effectively use big data. In some countries, such as Brazil, data is collected without consent and sold to third parties [18]. Cybersecurity protocols are also not always followed, leading to compromised security in digital infrastructure systems.

5.4 How Countries in the Global North Use Data to Promote Education Development

A collection of student data in schools in countries such as the United States of America (USA) is used to make informed decisions. This information includes student demographics, attendance, academic performance, health, disabilities, and participation. Each school district then stores this data in large student databases, which are analyzed to identify issues and make informed decisions. Furthermore, the allocation of resources to each school is determined based on the data. The data from each district is compared to that of other districts to determine which schools/districts require intervention. The data is also utilized to create policies and legislation to protect the well-being of students and teachers [19].

5.5 Technologies that are Being Used in the Education Sector in Both the Global South and Global North

The COVID-19 pandemic led to an increase in the use of technology and digital devices as alternative modes of learning and teaching, replacing the traditional classroom approach. At the height of the pandemic, many schools and institutions, particularly in upper-middle to high-income areas, switched to a fully online mode of teaching and learning. Even today, many schools and institutions worldwide practice a hybrid approach that combines traditional classroom teaching with online teaching. This approach makes it easier for countries in the Global North to transition from the traditional classroom approach. However, for countries in the Global South, this transition is only feasible in upper-middle to high-income areas, as financially disadvantaged individuals may not be able to afford such changes [20].

To enable a hybrid mode of teaching and learning, educational institutions have been advocating for e-learning through mobile digital technologies. With this approach, students can access online lessons, quizzes, tests, exams, and other content from their mobile devices, such as cellphones, tablets, and laptops, ensuring uninterrupted academic progress. This virtual learning method utilizes cloud computing, enabling students to access academic content from any device, anywhere in the world. It also enables teachers to collaborate and share resources while reducing the time it takes to grade students' work, as certain online content can be automatically marked by e-learning platforms [21].

The use of Interactive Smart Boards is not a new technology and has been implemented even before the onset of the COVID-19 pandemic, and still in use today. These tools use a digital projector alongside a computer to showcase content onto the Smart Board, which can be interacted with directly by the user. Utilizing these Smart Boards results in numerous advantages, including more significant engagement by students, improved problem-solving, and an overall easier teaching method for educators [22].

Although these technologies are popular and useful in the Global North, as well as in upper-middle/high income areas of the Global South, they remain inaccessible to many poor individuals. Educational institutions can attempt to bridge the gap by providing mobile devices to these students, but this may not be enough as many individuals lack the technical skills to use these devices. Furthermore, schools in rural areas may not have the resources to provide students with such devices, which hinders their academic progress compared to their wealthier peers [23].

Although online learning has gained popularity, it also has some limitations. Some individuals may find it difficult to adjust to this mode of learning due to factors such as limited technical skills or disabilities. Additionally, e-learning offers a less interactive approach than traditional classroom learning, which can lead to more distractions for students. While e-learning has provided a new and sustainable mode of education, there are still many who prefer the traditional approach [22]

5.6 Increased Student Enrolments in the Global South

According to recent research, the number of higher education students worldwide has grown significantly, with the majority of the increase occurring in the Global South, primarily due to higher education institutions in India. However, in the Global North, student enrollments in higher education institutions have been declining since 2011. Funding has also increased globally, but there is a difference in the focus of funding between the two regions. In the Global North, funding is primarily directed towards research, equity, and quality, whereas in the Global South, it is focused on enhancing accessibility and capacity. This disparity underscores the quality gap between the two regions [24, 25]

5.7 The Changes that Access to Data can bring about in the Global South

Effective government policies and digital resources are key drivers in promoting data access in countries. With supportive regulations, a strong digital environment can be created, allowing for the establishment of digital infrastructure and reducing the digital divide. Examples such as China's State-led Model and Europe's Regulatory Model demonstrate how government support can foster long-lasting digitalization goals [1].
By promoting data access, the obstacle to Internet accessibility can gradually be diminished. To promote access, many developing countries are expanding coverage and investing in broadband initiatives. Several South American and Asian nations have already completed 5G technology initiatives. While government support is essential, foreign investments are a significant driving force behind progress in accessibility. Major technological companies, including Google, are known for investing in global

initiatives for Internet accessibility and connectivity, particularly in Africa. Such investment opportunities can foster skills development and employment opportunities [26].

The education sector is significantly affected by the increase in data accessibility. With improved access, more people can access e-learning platforms and improve their technical skills and academic progress with less difficulty [1]. Although digital transformation projects require substantial support, resources, and funding, they can lead to beneficial outcomes, including educational and other forms of development [27].

5.8 Implications of the Study

The study's findings highlight the potential of data access to promote education development in the Global South, drawing from previous research to demonstrate that over 50% of primary and lower-secondary school-aged children worldwide are not proficient in reading and basic mathematics. The findings also suggest a growing demand for tertiary education in the region, with an increase in the establishment of higher education institutions. However, the quality of education provided by these institutions is often hindered by inadequate funding. This study can be used to identify reasons for limited data access in the Global South and to generate potential solutions. Moreover, it indicates the need for further research on the underlying causes of data access limitations.

5.9 Limitations of the Study

The primary focus of this study is on the impact of technological limitations on education development in the Global South. However, the estimates used to determine the number of school-aged children worldwide who do not attend school are not precise measurements but are based on surveys and censuses. Additionally, the research is limited to English-language publications or those with English translations, and other non-English publications that could provide valuable insights have not been explored. Another limitation is that the study looks at the Global South as a whole, which may not accurately reflect the unique educational and technological situations of each country and household.

5.10 Recommended Future Research

The research conducted in this thematic analysis has identified several areas where further research and analysis could be beneficial:

1. Although the review examined the overall education and data disparity in the Global South, it did not delve into the specific causes and effects of limited data access and education in each region. Future research could focus on conducting a thorough analysis of individual countries' education and data access situations in greater detail.
2. The discussion regarding the percentage of children in primary and lower secondary school who lack formal education relied on statistics from 2017 and 2021. In-

corporating more recent data from 2022 would be beneficial for future research endeavors.
3. While the review addressed the global increase in higher education students, there is a need for further analysis on the status of tertiary education in the Global South. Additionally, future research could explore the percentage of high school-aged children who do not receive formal education.
4. The review highlighted the importance of foreign investment initiatives in driving digital development in developing countries. However, future research could specifically examine the types of foreign investment initiatives that have propelled digital development and data access in developing countries thus far, as well as their effects.
5. Lastly, discussions on digital education often touch upon the intersection of data access limitations and education development in the Global South. Although there is a substantial amount of research available on both the Global South and its digitalization efforts, there is still a significant research gap specifically exploring the relationship between data access and education development in the region. This thematic analysis suggests potential areas for future research that can lay the groundwork for future projects and offer valuable insights into short-term and long-term solutions for developing countries. Conducting such research could facilitate positive change and drive advancements in the region.

6 Conclusion

This thematic analysis provides insights into the impact of data access limitations on education development in the Global South through the analysis of 30 studies. The literature identified a number of gaps, including the role of the digital divide, online learning, and the future of E-learning technology. The thematic analysis firstly examined the current state of education in the Global South, revealing that more than 50% of primary and lower-secondary school-aged children worldwide lack access to quality education, with a majority belonging to low-income countries. Particularly, Sub-Saharan Africa faces the highest number of primary school-aged children without adequate education. Secondly, the review delves into the state of data access in the Global South, indicating that less than 50% of the population in low and middle-income countries can access the Internet due to factors such as affordability, limited infrastructure, and technical skills. Thirdly, it explores the use of e-learning technologies and the integration of big data in the education sector. The review highlights the use of online learning management systems, hardware, and big data analytics as means to improve educational outcomes. It emphasizes the importance of strong government support and foreign investment initiatives in driving digital and education development, bridging the digital divide, and ensuring ethical and productive use of big data. While some countries in the Global South may lag behind developed nations in terms of digital advancement, they have shown progress and aspire to experience growth in both digitalization and education in the future.

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Appendix 1: Data Extraction Table

Citation	Name of Journal/ Conference	Database	Research Strategy	Sample and sample size	Criteria/Concept/ Dimension	Main criteria, concepts, dimensions
(Adrees, et al., 2015)	International Journal of Database Management Systems	Google Scholar	Analytical	Sudan as a model	Cloud computing architecture; cloud computing education	Cloud computing; higher education; third-world countries
(Werthner, Prem, Lee, & Chezzi, 2022)	Book	Google Scholar	Analytical	N/A	Lack of inclusion; colonialism; COVID-19; online education	Digital divide; digital access, ICT4D
(Dados & Connell, 2012)	Contexts	SAGE Journals	Analytical	Countries in the Global South	Power relations; inequalities	History of the Global South
(De Bastion & Mukku, 2020)	Report	Google	Descriptive and qualitative	N/A	Inequalities; data governance; digital models	Global South; digital development; USA, China, EU
(Langthaler & Bazafkan, 2020)	Briefing paper	Google Scholar	Analytical	Global South – Sub-Saharan Africa	ICT; 4IR; COVID-19	4IR, digital skills; digitalization
(Schopp, Schelenz, Heesen, & Pawelec, 2019)	TATuP	Google Scholar	Analytical	Global South - Africa	Colonialism; barriers; gender digital divide	Neo-colonialism; power relations; barriers to access; digitalization
(Vedder, 1994)	International Review of Education	Google Scholar	Analytical and Qualitative	N/A	Educational systems	Developing countries; education; global education measures

The Adverse Effects of Excessive Social Media Use During The Pandemic: A Structured Literature Review

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Abstract. There is much research on the adverse effects of social media use during Covid-19. However, few research papers summarise multiple adverse effects, possible root causes and how these variables interlink with overall well-being. Social media played a vital role during the Covid-19 pandemic and changed many people's perceptions of the virus. Subsequently, social media use and the amount of information about the virus became unfathomable. This systematic literature review identified 34 research papers from the existing social media body of knowledge. The significant outcome of this paper is a synthesis of the most recurring and studied adverse effects of excessive social media use during the pandemic. The adverse effects include cyberchondria and information overload, an increase in anxiety, an increase in social media addiction, an increase in stress, lower academic grades, and an increase in depression. The root causes of these adverse effects were identified and are, using social media as a coping mechanism, as a way to connect, as a way to receive Covid-19-related information, using social media to decrease the fear of missing out, reading fake news, misinformation and the Infodemic, and using smartphones and social media in problematic ways. This paper serves as a baseline for future research into users' excessive use of specific social media platforms during pandemics and how social media can influence users' behaviours and potentially alter the outcome of significant world events.

Keywords: Excessive Social Media Use; Adverse Effects; Well-being; Covid-19 Pandemic; Systematic Literature Review

1 Introduction

In 2020, the Coronavirus (Covid-19) pandemic started and created a social disruption unlike anything the digital world had ever seen before [1]. Individuals were forced to isolate themselves from physical contact with the outside world. As a result, social media usage was at an unprecedented high, mainly to combat the feelings of loneliness that took a toll on people's psychological and physical well-being [2, 3]. The stressful times of Covid-19 made people look for distractions and coping mechanisms in any way possible, leading to increased screen time and, subsequently, social media use [4]. Statista Research Department released an online graphic indicating that in 2020 there were 3.96 billion social media users [5]. This number grew exponentially

since then, and as of 2022 4.59 billion people use social media. Social media drives globalisation and enables users to break down barriers that once limited interaction on this scale [6]. The daily interaction needs of individuals have increased significantly, especially in an isolated Covid-19 era [2]. Individuals constantly needed to see what is going on in the world and what is happening in other people's lives. This also leads to an increased fear of potentially missing out on beneficial opportunities and events, a phenomenon known as Fear Of Missing Out (FOMO) [1].

Social media is free and accessible for most people [7]; therefore, the amount of opinion-based, false information increased, and the Infodemic relating to Covid-19 information proliferated during the pandemic [8]. As a result of the Infodemic, individuals potentially developed information overload, which increased their adverse effects experienced such as anxiety, stress, and eventually, social media addiction [3, 9, 10].

The purpose of this review is to identify the main adverse effects that excessive social media use had on the well-being of individuals, during the Covid-19 pandemic. This paper also aims to identify the root causes for excessive use of social media that lead to potential adverse effects as well as identify and discuss the social media platforms most used during the current Covid-19 pandemic. Against this background, the following research question is answered:

What are the main adverse effects that impact users' well-being due to excessive social media use during the Covid-19 pandemic?

In support of the main research question, the following sub-question were answered:

- What are the root causes of excessive social media use that lead to adverse effects?

Due to page limitations, this research paper will specifically focus on social media's negative impact on users during the Covid-19 pandemic. The sections following will describe the data-gathering process in detail. After that, the findings section will provide insight into different factors that negatively impact individuals' well-being. The last sections will reflect on the systematic literature review, and recommendations for future research will be discussed.

2 Research Method

The research method used in this paper is a Systematic Literature Review (SLR). A systematic literature review is a secondary research paper used to summarise key findings from other research papers to answer the formulated research questions [11, 12]. Research is collected from many different databases and data sources using search terms. The results of the database searches are then filtered down using the inclusion and exclusion criteria. The identified research papers are then read in full to assess the quality of each paper [12]. Once the high-quality research papers have been identified, a proper data analysis method is then used to identify the important codes and themes [12, 13]. After that, the review is written based on the key findings of the data analysis to identify potential gaps in the research and to answer the research

questions [12]. Papers were collected from the following databases: ScienceDirect, Web of Science, Scopus, PLOS One and SpringerLink.

The following search terms were used: (“negative” AND “adverse” AND “effects” OR “consequences” OR “impact” AND "excessive social media use" OR "social media addiction" OR "problematic social media" Or "exposure" AND "Covid-19" AND "well-being" AND "mental health" AND “health”).

The ScienceDirect database limits the number of Boolean connectors, therefore a summarised search string was created to fit the database specification.

(“negative” AND “adverse”) AND ("social media use") AND ("Covid-19") AND ("well-being" AND "mental health"). The search terms were used and only papers that had these terms in their title or abstract were considered for this paper.

The Covid-19 pandemic started in December 2019; therefore only articles published from 2019 to 2022 were included. Furthermore, only articles written in English that were peer reviewed and were in line with the research question were considered. All papers that discussed the positive effects of social media were excluded, as well as all papers where the full text was not available.

The search strings were typed into the databases used, and 1573 papers were displayed. Additional papers were identified as the researcher read through papers and found in-text references that could contribute to this study. These 174 papers were added to the total, which brought the main total to 1747 research papers. The duplicate research papers were identified and removed, bringing the total to 1572. After that, the titles of the papers were read, and any titles not containing the strings “Covid-19,” or “Pandemic” or “social media” or “adverse” were discarded. This narrowed down the number of research papers. However, many papers remained, making reading the full texts impractical. Therefore, the abstracts were read to determine if the research paper would answer the research questions for this study. After that, 129 papers were read in detail to determine if the papers answered the research questions. Based on that, 95 papers were excluded, and 34 papers were used to answer the research questions of this study.

The quality assessment for this Systematic Literature Review is completed to ensure that the data collected was as unbiased and complete as possible. All 34 papers were evaluated and given a score. Zhou, Zhang [14] identified the most useful and applicable quality assessment criteria questions, which guided the creation of the quality assessment questions for this study. The articles scored between 3 and 5. No articles were excluded after the quality assessment was completed, therefore indicating that the papers were of high quality.

3 Data Analysis

This Systematic Literature Review used Thematic Analysis as the data analysis method. Thematic Analysis is a qualitative data analysis method used to thoroughly analyse data to identify applicable codes within the research, combine the identified codes into different categories relevant to the research question, and identify themes across multiple research papers [15]. Therefore, aiding in the synthesised nature of

this SLR. Thematic Analysis comprises six steps, namely, becoming acquainted with the data and research selected, identifying codes while reading the data, grouping the identified codes into themes or collections, and assessing the themes to ensure they are adequate and relevant to the research question, naming and describing themes, and writing the synthesised review [15].

For step one, each research paper was read in full and highlighted, the most important information was added to an Excel spreadsheet, and a code word was written in a cell next to the information. This made step two easier to complete. As more research papers were read and the information extracted, identifying key codes in the sentences became easier. After all the research papers were read, step three was completed, identifying the main themes, and grouping the information extracted accordingly. The groups or themes identified were the adverse effects of social media use, root causes of increased social media use and social media platforms. The codes were sorted into the correct theme. The themes identified answered the research questions. This completed steps four and five, and after that, the systematic literature review was written based on the codes and themes identified in the data extraction table.

4 Findings

After searching multiple databases and performing a thorough analysis and quality control of the research papers, 34 were identified and used throughout this study. The final 34 research papers consist of 33 primary and one secondary research paper. The primary studies had various data collection methods, including questionnaires, and online surveys. Two papers research was conducted in Africa, 16 in Asia, one papers research was conducted in Australia, 13 in Europe and five papers research was conducted in North America.

4.1 Increase in social media use during the Covid-19 pandemic

First, it was essential to determine if there was an increase in social media use reported during the pandemic. Social media use increased throughout the different phases of the Covid-19 lockdown. This statement was supported by five research papers.

Tao, Chen [3] indicated that 37% of their survey respondents reported increasing their social media use by more than three and a half hours weekly during the pandemic. The respondents social media use increased by 4.2 hours a week. This study also reported that females showed a more significant increase in their time spent on social media compared to males, during Covid-19. In a study by Werling, Walitza [16], parents of children admitted into psychiatry in the last two years had to answer questions about their children's social media use during the Covid-19 lockdown period. This study found that 43% of female patients, who were 14 years or older, used social media for more than four hours daily during the lockdown period. However, this was only true for 17% of the males of the same age. The total increase in social media use from prior to the pandemic to peak lockdown was 45.3%. This study reported that

increased time spent on social media returned to their usual numbers post-lockdown. Boursier, Gioia [2] reported that only 7.4% of the respondents indicated that they spent more than four hours per day on social media before the lockdown. However, this percentage increased to 21.2% during the lockdown. The respondents' average time spent on social media during the lockdown was three and a half hours daily. In a paper by Nilsson, Rosendahl [17], the respondents average hours spent daily on social media was 3.9 hours for males and 5.6 hours for females. This study indicated that female and male respondents admitted to increasing their social media use during the pandemic. The percentages were 55.9% and 34.3%. In an analysis of tweets posted during the Covid-19 pandemic, Valdez, Ten Thij [18] determined that the number of tweets increased significantly during the onset of the pandemic and the first phase of lockdown.

Based on the above information, it can be determined that social media use increased for many users during the Covid-19 pandemic and that the average user of social media spent more than three hours daily on social media during the Covid-19 lockdown. Thygesen, Bonsaksen [19] found that 20.7% of the total sample indicated that they used social media for three or more hours a day. This was an international paper with research conducted in the United States of America, the United Kingdom, Norway, and Australia. Therefore, this further indicates a consistently above-average daily amount spent on social media all around the world.

The more time spent on social media, the more vulnerable individuals develop to adverse effects. An article by Hunt, Marx [20] indicated that the recommended amount of time spent daily on social media is 30 minutes or less. Otherwise, individuals risk negatively affecting their well-being. Based on the information in the research papers, the indication is that most individuals spent more than an average of three hours on social media daily during the pandemic. These individuals were, therefore, more at risk of experiencing adverse effects on their well-being.

4.2 Adverse effects on well-being. The adverse effects of excessive social media use during the Covid-19 pandemic were identified and can be classified into two main categories: Adverse effects on physical well-being and Adverse effects on mental well-being.

This section identifies and describes the six factors that adversely affected an individual's mental well-being during the pandemic due to excessive social media use.

4.2.1 Cyberchondria and Information Overload. The internet and social media provide access to an infinite amount of information, data, pictures, videos and opinions relating to Covid-19 [21]. A vast amount of information is uploaded and shared on social media every second, especially during isolation times. This can lead to individuals experiencing an information overload. This occurs when individuals cannot process the amount of information they are exposed to, fast enough [21]. Most people might experience information overload due to Cyberchondria, which occurs when someone obsessively searches for information about a particular health condition or symptom [8, 21]. Social media is an opinion-based, subjective platform that fuels cyberchondria and information overload [8].

Farooq, Laato [21] found that individuals who used social media as their main source to learn about Covid-19-related topics reported a significantly higher rate of information overload and cyberchondria, than individuals who used other, more credible sources. An analysis of generation Z (individuals born between the mid-1990s and early 2010) in the UK found that this age group was exposed to vast amounts of information relating to Covid-19 due to their social media use. This potentially led to individuals experiencing information overload, which caused gen z social media users to experience adverse effects relating to their psychological well-being, such as increased fear of Covid-19 and social media fatigue [22].

However, in some instances, information overload and cyberchondria can be helpful tools. Farooq, Laato [21] reported that cyberchondria and information overload contributed positively to people embracing the prescribed health and safety regulations to prevent the spread of Covid-19. Nevertheless, for people with high levels of cyberchondria, it could have a long-term adverse effect. It could potentially increase their anxiety and stress as they constantly look for reasons why they need to isolate [21].

4.2.2 Increase in Anxiety. Anxiety can be defined as the sense of worry, uneasiness, and fear relating to a particular matter or an unknown subject and can also be related to anticipating danger or dread [9]. The Covid-19 pandemic was a period of constant unknowns and fears, things changed rather quickly, and people did not know what to expect next [23]. Therefore, they took to social media to monitor and stay up to date with the latest news and developments. However, in return, they potentially increased their anxiety levels due to the content consumed on social media.

In a research paper by Gao, Zheng [24], 22.6% of the respondents indicated having anxiety, during the pandemic. This study also determined that individuals with increased frequency and exposure to social media had a higher likelihood of developing anxiety. Kim, Park [25] analysed tweets posted during the onset of the pandemic and found significant amounts of evidence of high anxiety levels among users, indicating that they were scared and skeptical about the virus. Higher levels of anxiety are seen as predictors of problematic social media use [4]. Bendau, Petzold [26] reported that individuals who used social media as their main sources of Covid-19 and pandemic related information reported substantially higher levels of unspecified anxiety.

Health anxiety is a concept used to describe individuals who experience anxiety relating to their own physical or mental health or someone else's health [27]. Some people might develop health anxiety due to previous experiences or other people's experiences and opinions [27]. Covid-19 was unknown, and most people had never experienced anything like it. People possibly took to social media to find positive information relating to Covid-19. However, if people came across negative information, their health anxiety worsened, and the constant search for positive information contributed to individuals excessively using social media [27].

The Covid-19 pandemic negatively harmed people with health anxiety in many ways [27]. As a person’s health anxiety increased, they feared missing out on important Covid-19 related information, that could affect their health and well-being [28].

4.2.3 Increase in Social Media Addiction. Social media addiction has become very prominent in recent years, and the Covid-19 lockdowns could have potentially increased that prominence. Social media addiction is the uncontrollable urge to view content posted on social media platforms [29]. This can eventually lead to overuse and the disruption of certain aspects of one's life [27].

In the research paper by Cleofas [6], one of the survey respondents added this quote, *"it's also become an addiction like it's a necessity, or something you can't live without it or do something without browsing first"*. This statement could potentially indicate that individuals did realise that social media was addictive. However, in some instances, it became a habit, and people subconsciously did it [29]. Rogowska and Libera [30] reported that 17.19% of their respondents admitted to developing an addiction to one of the most used social media platforms, Instagram, during the Covid-19 lockdown.

In a research paper by Tao, Chen [3], 6.8% of their survey respondents admitted to having a social media addiction during Covid-19. It further determined that men showed higher levels of addiction compared to females. Men reported 8%, and females only 6%. This study also revealed that people who spent more than 30 hours weekly on social media during the Covid-19 period were more likely to develop a social media addiction. Zhao and Zhou [31] reported that Covid-19 related stress had a significant effect on individuals developing active and addictive social media patterns. They explained that Individuals experienced Covid-19-related stress and started to use social media more frequently, which, in turn, created an addiction to social media.

4.2.4 Increase in Stress. Stress is a widespread phenomenon and occurs when an increase in demand makes one feel overwhelmed and beyond an individual's capacity to cope [32]. The pandemic had severe and devastating outcomes, shared all over social media, when individuals viewed this information, it might have made them more stressed. Three research papers determined that social media use increased stress levels during the pandemic, however, two papers indicated that social media use was used to relieve stress during the pandemic. Kelmendi, Beka [10] indicated that individuals' stress levels rose, due to increased Covid-19-related social media use. In the study, the biggest age group to use social media was 18-30 years, and this age group also reported higher average stress levels. Tao, Chen [3] reported that 10.8% of the respondents indicated moderate to severe stress levels. This study also determined that users who experienced moderate or severe stress levels used social media more and were higher at risk of developing social media addiction. Zhao, Ye [32] provided evidence that shows, when individuals experienced Covid-19 related stressors during the pandemic, they were more likely to use social media in problematic ways.

However, in some cases, social media use during the pandemic was a useful tool to manage stress levels, rather than increase them, people see it as a pause from the real world and can forget about their problems for a short while. Cleofas [6] studied the themes that emerged from student's social media use throughout the pandemic. They found that for 27.66% of the respondents, social media was essential to manage their stress levels. Dongke and Sannusi [27] also indicated that for some people social media is a stress outlet.

4.2.5 Lower Academic Grades. As the Covid-19 lockdown started, students were forced to move their academics online [33]. Previously students needed to attend class every day to interact with lectures in person. This made it easier for lecturers to monitor distracting behaviours of students. Sneaking a short social media break in class was more difficult than sitting in front of a screen listening to a lecturer that cannot see you scrolling on social media. Students were more distracted and, in an environment where nobody could monitor their social media use, like in the past [27]. This, in turn, could have potentially affected students' academic performance.

Homaid [33] determined that increased problematic social media use, increased technostress and exhaustion levels which then negatively affected academic performance. Jiang [9] concluded that students with problematic social media use during the pandemic had higher levels of anxiety and academic burnout. This paper provided a possible reason for that, was that students tried to escape their academic responsibilities by using social media to keep them busy and distract them from their academic work. However, on the contrary, 13.83% of the respondents in a study by Cleofas [6] indicated that social media helped them with their school and academic activities during the lockdown. They indicated that it provided them with a way to communicate with their teachers, and also noted that they found comfort and motivation in the fact that there were other student, also busy with school or university, across the world experiencing the same thing as them.

4.2.6 Increase in Depression. Depression is a mental condition that affects an individual's mood, thoughts and feelings and negatively affects one's quality and perception of life [34]. During the Covid-19 lockdown people were stuck at home and could not go and do things that would improve their mental health [4]. As a result, depression potentially increased, due to confinement and increased social media use. Tao, Chen [3] reported moderate to severe symptoms of depression in 18.2% of the people who responded to the study during the pandemic. The people who reported higher levels of depression were primarily males and people younger than 30. This study also revealed that people who had depression during the pandemic, had increased chances of becoming addicted to social media. Gao, Zheng [24] reported that 48.3% of their respondents reported depression symptoms during the Covid-19 lockdown, an increase in depression levels for individuals aged 21-40. This study found that individuals who used social media more frequently had a higher chance of developing depression. Another article by Islam, Sujan [4], reported that 38% of the respondents had depression symptoms. This study also indicated that the increased problematic use of social media, increased depression symptoms in people during the Covid-19 lockdown. El Frenn, Hallit [34] reported that using social media more, during the Covid-19 pandemic to read news, led to an increased frequency of depression symptoms. Bendau, Petzold [26] indicated that individuals who use social media as their main source of Covid-19 related information experienced significantly higher levels of unspecific depression. Individuals who use official verified websites to obtain Covid-19-related information had significantly lower levels of unspecific depression. They also found that as social media use increased, individuals' unspecific depression levels also increased. Individuals who reported using multiple different types of social media had higher levels of unspecific depression [26].

4.3 Adverse effects on physical well-being. This section identifies and describes the two factors that adversely affected an individual's physical well-being during the pandemic due to excessive social media use.

4.3.1 Less Physical Activity. Physical health is how well an individual's physical body performs while doing activities and how well an individual's body performs its functions, in order to increase physical health, one needs to perform physical activities [7]. During the Covid-19 lockdown period, people were confined to their houses, and it is possible that many people lived in places where their living environment limited physical activity. However, lower physical activity could also be as a result of increased social media use during the pandemic [35]. Ahsan and Hakim [7] indicated that individuals who experience social media addiction, find it more difficult to perform physical activities and therefore negatively affects one's overall physical health. A study by Islam, Sujan [4] indicated that 41.5% of their respondents did not exercise regularly, nor did they partake in physical activities during the lockdown. This study also reported that as problematic social media use increased, individuals also indicated lower levels of physical activity. Nilsson, Rosendahl [17], indicated that their respondent's social media use increased during the onset of the pandemic and as a result, their mental health levels started to decrease, and aspects such as regular physical exercise were negatively affected.

4.3.2 Lower Sleep quality/ Insomnia. Sleep is one of the biggest contributors impacting one's overall health [36]. During the Covid-19 pandemic, people used social media more, and as a result, their sleep quality and quantity potentially decreased, some individuals might have experienced higher levels of insomnia [36]. Insomnia occurs when an individual struggles to fall asleep [37]. Zine El Abiddine, A. Aljaberi [36] indicated that as individuals' problematic social media use increased during the pandemic, their levels of insomnia also increased and therefore, negatively affected their overall well-being. Nilsson, Rosendahl [17] reported that the most prominent negative effect of social media use during the pandemic was a negative influence on sleep. Homaid [33] concluded that as an individual's problematic use of social media increased, their exhaustion levels also increased.

4.4. The Root Causes of excessive social media use that lead to adverse effects

This section provides information on six root causes that led to the increase of social media use and adverse effects during the Covid-19 pandemic.

4.4.1 Social media as a coping mechanism. Many people had to isolate during the Covid-19 pandemic [6]. People were scared, stressed and alone and used social media as a coping mechanism to satisfy their interaction needs and increase their mental health [6]. Cleofas [6] added a quote from a respondent that said *"Social Media for me is entertainment. I can scroll and forget about my problems even for a while."* A different respondent from the same research paper also added the following quote, *"It also relieved my stress and helped me cope with the current issues around the world"* [6]. Thygesen, Bonsaksen [19] concluded that using social media as a coping mechanism to maintain connections was linked to increasing individuals' overall mental well-being. Valdez, Ten Thij [18] researched how tweets posted throughout the

Covid-19 lockdown affected people's mental well-being. This study concluded that people used Twitter more during the lockdown period as a coping mechanism for the isolation they were experiencing. A possible reason for this might be that Twitter is a conversation-driven platform. Therefore, people took to Twitter and partook in the discussion to potentially decrease loneliness levels during the isolation phases [18].

However, this led to people developing harmful, unhealthy, and potentially addictive-like coping mechanisms to deal with the lockdown stress and loneliness [2]. On the contrary, using social media as a coping mechanism increased anxiety levels. An article published by Zhao and Zhou [31] reported that individuals who actively and excessively used social media throughout the Covid-19 lockdown period, indicated that it acted as a dysfunctional and debilitating coping mechanism, which later escalated to social media addiction. Rogowska and Libera [30] also indicated that addictive Instagram use could result from users being lonelier during the pandemic, and they needed social media to preoccupy them.

4.4.2 Social media to connect. When the World Health Organisation declared Covid-19 a pandemic, people needed to go into quarantine. Some people were isolated from others—however, some isolated alone [38]. Regardless of people's living situations, feelings of loneliness possibly increased. Rogowska and Libera [30] indicated that 75.16% of their respondents were moderate to strongly lonely during the pandemic. This same study reported that 61.22% of respondents reported feeling emotionally lonely, and 46.54% of the respondents reported feeling socially lonely throughout the lockdown. Increased feelings of loneliness might have caused people to use social media as a way to connect to others. Cleofas [6] reported that 30.85% of their respondents used social media, mainly to preserve social connections during the lockdown period. One of the survey respondents added this quote, "*Social media keeps us connected to the world in a disconnected way"* [6]. A different respondent in this study also added this quote, *"It is my mode of communication to my friends and connecting myself to the social world"* [6]. This indicates that when people use social media to interact with friends, it serves as social interaction, albeit in the virtual online world. However, social media use to stay connected was only seen as a positive when people used it responsibly and for the purpose of connecting with others to maintain relationships [19]. This same study reported that when individuals used social media only to decrease loneliness, some experienced worse mental health effects. A shift started to occur when social media use to satisfy connectedness became problematic. Boursier, Gioia [2] discussed that during the lockdown period, people acted like problematic users, as they were constantly chasing the need to stay connected. Thus, excessively increasing their social media use could have led to developing addictive-live behaviours. Islam, Sujan [4] also indicated that excessive social media use might lead to problematic social media use.

4.4.3 Social media as a medium to receive Covid-19 related information. During the onset of the pandemic, social media was a helpful tool to quickly spread information about how people can protect themselves and avoid possible infections [26]. People took to social media to receive updates on what the World Health Organisation and other media sources suggested people must do [21]. As a result, social

media platforms became some people's primary source of pandemic-related information.

Farooq, Laato [21] found that 52.9% of their survey respondents reported using social media as their primary source for Covid-19-related news. Another study by Bendau, Petzold [26] reported that 49.9% of their respondents used social media as their main source of pandemic-related information, this possibly increased unspecific depression. In a study by Ahmad and Murad [39], 82.6% of their survey respondents indicated using Facebook as their most used platform for Covid-19 news. Laato, Najmul Isl [8] also indicated that 92% of their survey respondents indicated that Facebook served as their main source of Covid-19 information. The respondents in the survey conducted by El Frenn, Hallit [34] indicated that individuals spend between 2.25 and 2.65 hours a day on social media reading news related to Covid-19.

Bitkina and Park [38] indicated that their survey respondents looked for Covid-19-related updates more at the start of the pandemic, and throughout lockdown, compared to post-lockdown in September 2021. This study also reported that the individuals could notice a change in their emotional state when they read the information relating to Covid-19, especially at the start of the pandemic. This study also indicated that viewing Covid-19 related content made their anxiety and their stress increase.

4.4.4 Misinformation, Fake News and the Infodemic on social media. Misinformation is false information that is generated and shared without the intention to hurt or deceive people [22]. Fake news can be defined as a piece of information with no evidence to support the statement, and it is created and shared knowing that the information is false [8]. During the pandemic, individuals might have read the information on social media, assumed it was factual, and passed the information on. In most cases, misinformation or fake news gets more attention than factual information, because individuals tend to respond more to emotion-provoking reports [25]. Fake news and misinformation could also distort the reality of the situation and make people panic [40]. A study by Ahmad and Murad [39] asked respondents which category of news shared on social media made them panic the most; 26.6% of respondents indicated that fake news relating to Covid-19 made them most fearful and increased levels of panic. Many people knew that information shared online could be false. A study by Cleofas [6] added a quote from one of the respondents who said, *"Social media is very important nowadays because of the information we can collect but be mindful that sometimes there is fake or unreliable information..."*. However, most people did not know which information they read was factual or false. Therefore, the World Health Organisation stated that we are currently fighting the Covid-19 pandemic, as well as an Infodemic [8, 22, 39]. The Infodemic relating to Covid-19 information, misinformation, and fake news made people more anxious and scared of the virus, and therefore potentially increasing health anxiety and cyberchondria [21, 28].

4.4.5 The Fear Of Missing Out (FOMO). The Fear Of Missing Out (FOMO) can be described as the feeling of potentially missing out on opportunities, events that other people are experiencing, as well as an overwhelming urge to know what other people are busy with [35]. Brailovskaia, Stirnberg [35] reported that people who do not fulfil these desires might become anxious, stressed, and frustrated. One of the main characteristics of the Covid-19 pandemic was the lockdown. Individuals might

have developed FOMO relating to Covid-19 information, as they constantly needed to ensure that they were not missing out on information relating to Covid-19, that was very important [28]. Missing out on important health related information could have potentially increased their levels of health anxiety [27]. Elhai, McKay [28] provided evidence that there was a positive relationship between people experiencing health anxiety and FOMO. This indicated that as individuals health anxiety increased their FOMO increased, as they were scared to miss out on important Covid-19 related information. Brailovskaia, Stirnberg [35] indicated that as individuals experienced higher levels of FOMO, their problematic smartphone use also increased. Zhao, Ye [32] provided evidence that shows that FOMO during the pandemic had a mediating relationship between Covid-19 stressors and the increased problematic use patterns of social media.

4.4.6 Problematic smartphone use and problematic social media use. Many people's social media addiction potentially starts with first developing problematic smartphone use. Problematic smartphone use occurs when an individual develops a dependency on their smartphone, which leads to problematic consequences such as withdrawal, irritability and changes in mood [35]. This study found that as problematic smartphone uses increased an individual's sense of control decreased. The more time spent on a smartphone, the higher an individual's chances of developing problematic smartphone use are.

Problematic social media use can also be referred to as disordered social media use [6]. The definition is similar to that of problematic smartphone use. However, this problematic use refers to individuals who develop a dependency on social media platforms [6, 35].

Problematic social media use can potentially increase levels of stress among people as well affect multiple facets of one’s life which lead to well-being. Di Blasi, Salerno [41] indicated that individuals who experienced increased problematic social media use during the pandemic, reported having higher levels of psychological distress. When problematic social media use increased, individuals' experienced higher levels of exhaustion which in return decreased their academic performance [33]. Islam, Sujan [4] indicated that as problematic social media use increases, individuals experience lower levels of physical activity, poor academic management, and anxiety and depression.

Zine El Abiddine, A. Aljaberi [36] indicated that individuals who reported higher levels of problematic social media use also had lower overall well-being levels. The same study found that people with higher levels of problematic social media use also had higher levels of insomnia. This indicates that problematic use of social media leads to higher levels of insomnia, reducing sleep quality and overall well-being. Sleep dramatically affects mental well-being and could make it more difficult for people to cope with the high mental demand of a worldwide pandemic [36].

5 Conclusion

This systematic literature review analysed and summarised the findings of 34 research papers regarding adverse effects individuals experienced, due to excessive social media use in the Covid-19 pandemic. These research papers were found in five different databases and were published from 2019 to the present. Extensive research indicated a significant increase in social media use and content posted on social media. This study identified and summarised the most frequently discussed and studied adverse effects. The adverse effects include cyberchondria and information overload, an increase in anxiety, an increase in social media addiction, an increase in stress, lower academic grades, an increase in depression, lower quality sleep and less physical exercise. This paper provides a broad overview of the adverse effects by identifying root causes that potentially led to the development of the adverse effects. These root causes include using social media as a coping mechanism, to connect, to receive Covid-19 related information, using social media to decrease the fear of missing out, reading fake news, misinformation and the Infodemic, and using smartphones and social media in problematic ways. This research paper is in line with previous research. However, only a few studies aimed to investigate how different adverse effects interlink.

Social media is a big part of people's everyday life; therefore, many other adverse effects were identified but not included in this study. The results presented in this study are helpful for social media users, the information technology sector, and academics. It helps users make sense of the adverse effects they experienced.

Possible limitations of this paper include the fact that there were more female than male respondents. This could have affected the outcome of the results. The findings of this paper may be used as a baseline for academics to identify new and possibly more critical adverse effects and how social media use, in general, adversely affects an individual's overall well-being. This paper also provides information that can be used in preparation for the inevitable future pandemics.

6 Recommended future research

Future research based on this paper should focus on determining if the identified adverse effects could have a lasting impact on people beyond the pandemic. This paper should be used as a baseline for creating models for future pandemics to try and prevent the same adverse effects from occurring. More research should be done on the addictive nature of social media platforms and how the interconnectivity of the platforms causes addiction in people who feel or experience loneliness during isolation times. Research should be done to determine if the most used social media platforms are specifically designed to be more addictive during pandemics and what makes these platforms more addictive than others. Based on the indication that females used social media more than males during the lockdown period, more research should be done on why one gender might use social media more than another gender.

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Shadow Information Technology in the Advent of Open Educational Resources

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Abstract. The emergence of open educational resources (OER) promotes open access to widen information access as part of smart learning in higher education institutions. This causes higher education institutions to rely on shadow information technology (SIT) for information access and service delivery – to the point of shadow IT principles contradicting open education principles. In the event of adoption and development of OER, academics, developers and students opt for different software or system software, based on the usability and preferences of the system. Higher education institutions (HEIs), such as the University of South Africa (UNISA), are still conscious of the IT policy in terms of the appropriation of prescribed information and communication technology (ICT). This study opted for a qualitative research approach. The innovation diffusion theory was used to investigate the opportunities and challenges encountered by academics in the utilisation of shadow IT in the advent of OER. The data source was academics responsible for tuition and research. For data triangulation purposes, documents such as ICT policy, tuition policy, and comprehensive open distance e-learning (CODeL) policy were considered. The study established that the advent of OER can dismantle shadow IT prescriptions. This was elicited during the adoption and development of academics' use of different systems and software to create OER suitable for their tuition. This is an indication of academic stakeholders continuing to break the shadow IT roles, consciously or unsuspectingly, by being innovative, while complying with the institutional mandate of open access in education. Therefore, the revision of institutional ICT and tuition policies need to widen the scope by taking cognisance of both OER and shadow IT concurrently.

Keywords: Shadow information technology, open educational resources, CODeL

1 Introduction

Since the arrival of open educational resources (OER) in the education sphere, shadow information technology (shadow IT) has been receiving global attention. Academicians subconsciously or consciously use shadow IT when appropriating OER for

teaching and learning. The term *shadow IT* is defined as supplemental systems installed by users to the nominally supported systems provided by the organisation [1]. Alternatively, shadow IT is the software or hardware present in a computer system or network that lies outside the typical review process of the responsible IT department [2]. In the last decade, shadow IT has been associated with potential risks and vulnerabilities involved in unauthorised access, loss of data and services, and disclosure of private organisational information, while the benefits of shadow IT are gradually being recognised. In higher education institutions, academics or students turn to rely on digital technologies and ICT, because they want to improve the decision-making process for tuition businesses [4]. In the current era of the Fourth Industrial Revolution (4IR), academic institutions exemplify the circumstances supporting the growth of shadow IT, including extensive technological proficiency, financial independence, an open learning environment, high levels of collaboration [2], and appropriation of OER.

Open educational resources (OER) are teaching and learning resources that are copyright embodied and accessible in digital platforms including shadow IT. These resources are considered Internet-enabled; particularly because of the emergence of open courseware, OER, and open educational practices [4]. OER can be appropriated in online learning through the use of technology, such as Internet access through the use of smartphones or laptops. In the current era, these resources are intensely used and different digital or virtual platforms are used for global collaboration. ICT is connected with the adoption and development of OER in academia [54]. Therefore, in the absence of ICT, including shadow IT, the livelihood of OER may be in vain. OER makes more diverse and flexible learning possible and offers more access to low-resource countries [5].

The OER phenomenon has been widely researched in different contexts of education. However, studies on the appropriation of OER through shadow IT are less reported. The emerging literature relates to shadow education [6] and shadow economy [3]. Therefore, there exists a gap in the knowledge field. Therefore, in this setting, the relationship between OER and shadow IT is important because several ICTs are used while appropriating OER. What ICTs are most frequently employed or appropriate in the process is not yet completely understood. However, the shadow IT does not adequately document OER. As a result, the study set out to investigate how shadow IT was used in a comprehensive open distance e-learning (CODeL) university. This study opted for Roger's diffusion of innovations theory more details about are unpack in Section 3 (theoretical underpinning).

2 Literature review

2.1 Knowledge of OER

The appropriation of OER knowledge is crucial, since the effective use of OER may be hampered by a lack of understanding. When academics wish to embrace OER suitable for instruction and research, it becomes a barrier resulting in problems [10]. The "knowledge" phase refers to the idea of information affecting utilisation in any

particular context [8, 7]). It is recognised that there is still little awareness of OER on a global scale [11]. It is not unexpected that there are low levels of OER utilisation, given the current state of global OER knowledge. OER has been declared as an emerging phenomenon [12] and numerous organisations, including HEIs, are still equipping themselves with knowledge of OER.

Lately, the knowledge of OER, including the platforms of access, is known in education spaces. These resources also enable, promote and develop educational quality and equity that fit the educational demands of the knowledge society [6]. The level of OER knowledge varies, because, although the potential of OER in education is recognised, the literature opines that individual and contextual factors – such as teachers' intentions and attitudes regarding their use of digital learning materials [13], which include the different spaces in which OER are retrieved – may impact on the knowledge of OER. In spite of prior research findings reporting on areas of low uptake or knowledge of OER, a gradual change has been occurring recently that demonstrates that both staff and learners use OER and are knowledgeable of OER, due to continuous academic interventions, such as conferences, workshops and professional development [14].

2.2 User perceptions about OER

Because users typically have various perceptions of other IT artifacts, it makes sense that they would also have different perspectives of OER. According to the research, numerous academics and institutions support OER for use in teaching and learning [15]. This is made clear by the fact that the availability of OER resources in a variety of formats has expanded for use in instruction and research [16]. This gives academics the freedom to decide whether OER applies to their work. OER appears to be equally excellent, or better, than traditional textbooks in terms of quality and engagement. OER in video format is the most appealing to academics and students [17].OER is globally recognised as a great initiative to increase access to affordable education. Currently, the purchasing of textbooks is extremely costly and not all students can afford to buy these materials. OER have been identified as a solution to the high costs of traditional course materials [18]. In this way, OER is commended for cost saving, while offering similar or better outcomes in terms of student grades [19]. The literature affirms that academics' and teachers' perceptions of the use of OER lead to the significant benefit of improved student performance [20]. That is why numerous academics and teachers have a positive attitude towards OER, which motivates the use and sharing of resources for unselfish reasons [21]. In terms of education, all institutions profit from OER [22]. By virtue of open access online, users like academics and students, as well as specific types of institutions, such CODeL institutions, where teaching and learning priorities are fostering open access, benefit from the use of OER [23]. This can be a sign that easily available and practical educational resources promote transparency. Individuals, who are unable to afford to buy instructional materials or learning resources, can benefit from this transparency [27]. In order to use them, users have to become interested in OER, which is why HEIs have to make efforts to draw new students while encouraging OER use, and academics should consider the new strategies of marketing and enforcing OER in the curriculum [24]. In-

terest in OER can be created by developing user-friendly and easily accessible OER [25] which should gradually perpetuate interest. On the other hand, not all academics are supportive of OER. According to the literature, top-down pressure from managers enforcing the use of OER leads to academics feeling demotivated and disempowered [26]. HEIs continue to impose OER on academics without considering some of the obstacles confronting them. For example, numerous academics are still unaware of what OER is or how to incorporate them into teaching and learning [27]. Many HEIs and academics continue to struggle with accessibility and usability concerns [28]. As a result, these perceptional mismatches about OER may continue to cause issues with OER use.

2.3 Implementation of OER

Planning and conceptualization can occur in numerous organisations, however, starting the implementation process may be difficult. Implementation is the stage that results in the use of OER [7]. Without consulting the institution and doing a full inquiry – which includes an analysis of the existing circumstances and the way in which OER are affecting modern society – implementation cannot take place. All these new educational innovations are imported into the vast majority of developing nations in the Global North [30]. The status, education, and character of the populace must be taken into account ([30]. If not taken, it may lead to a decrease in the use of OER. For instance, prior to implementation, one should consider the influencing elements, such as the fact that most people in underdeveloped countries lack the necessary pedagogical and technological abilities [31], which have an impact on the use of OER. The foregoing information makes it evident that OER implementation needs to be reviewed or redone, in order to ensure that the resources are appropriate for the current context and to improve OER utilization.

2.4 Adoption and development of OER

Once users have acquired knowledge, expressed their perceptions, made decisions, and experimented with artifacts, they start to feel at ease and begin adopting OER. Adoption essentially involves incorporating OER into the existing module content. In order to support effective education in institutions, adopting OER in teaching and learning necessitates incorporating the most suitable resources [32]. To match OER with course requirements, the applicable course outlines have to serve as a reference for OER developers or integrators. The existing inability to search for and identify pertinent and useful OER from a variety of sources is one barrier to the widespread adoption of OER [33]. The search process may contribute to the adoption of OER because the online search process requires a particular knowledge and skill level.

At any HEI, users are either required to adopt OER or to create their own OER. The open pedagogy model must serve as a roadmap for the adoption and development of OER in any course content [34]. Because integration enables the infusion of supplemental sources (without additional expenditures) that may be helpful to anybody, using OER in teaching and learning opens new possibilities for improving education and provides users with more resources [11]. The acceptance and development of

OER have had a significant impact on countries in South America, sub-Saharan Africa, and South and Southeast Asia in terms of access to educational resources, the quality of teaching and learning, and the costs of education provision in the 21st century [35].

Open access is encouraged in higher education because after adoption and development, it increases students' understanding of educational material. Additionally, open access encourages worldwide collaboration and timely Internet visibility [36]. However, because European nations have more advanced digital links, institutional guidelines, and incentives and prizes for academics who adopt and incorporate OER [37], they cannot be compared to underdeveloped nations.

Collaboration among academics and HEIs typically occurs in developing nations, such as South Africa [38]. Academics continue to encounter hurdles in the provision of OER, including knowledge and talent gaps, time restraints, technical limitations, and other challenges [12]. In light of these impeding factors, academics and educators think about hiring a third party to generate OER on their behalf [39]. The usage, rationale, and standards of OER may be negatively impacted by allowing external stakeholders to incorporate or embrace new content. It is crucial for academics to embrace and grow OER into their practice, material, or subjects, despite the difficulties and barriers, since doing so fosters understanding and raises awareness of what OER are and how they may be used [40].

2.5 Dissemination of OER

When OER has been adopted and developed, the process of dissemination has to start. Academics have to publicize the developed OER so that they can be made available in the public domain, as the essential purpose of OER is to be accessed openly [13]. Apart from being continuous, dissemination is a process that occurs daily – particularly if the digital space is involved. Once OER reach virtual spaces and they are shared openly, they start a circulation chain. Institutions and academics are responsible for the dissemination of OER so that it can be shared among other institutions globally [41]. Institutions need to disseminate their output because they become relevant in the world of knowledge.

Different national practices govern the dissemination of OER. For instance, several educational institutions in Afghanistan contract with OER producers, including non-governmental organizations (NGOs), to create teaching and learning materials [42]. Due to their lack of expertise and a lack of an open sharing culture [43], these organizations often fail to publish their resources. Because academics or educators are still unsure of the actual dissemination processes used by their institutions, using a third party to generate OER is frequently fraught with difficulties [40].

The literature opines that the dissemination of OER can be done through technology strategies, including institutional repositories and websites, subject-specific repositories, sites for sharing specific types of content (such as video, images, and e-books), general global repositories [44], as well as any other shadow IT. However, determining the exact systems used for the dissemination of OER is still a problem at South African HEIs. This may affirm that the existence of OER is new across the globe [45],

however, it also serves as a wake-up call to developed countries, because they are exposed to numerous different OER dissemination facilities.

It is impossible to say which OER dissemination method is more preferred in the South African environment. Users face a challenge since they do not know which platform, system, or channel they can use to visualize published OER because every institution uses a distinct method of OER dissemination. Because academics at different institutions implement OER dissemination in diverse ways, there is a critical need for research to account for all user preferences.

3 Research context

The research context is the University of South Africa (UNISA), which has been changing its identity more than three times since the beginning of the 21st century. This institution has been described as a distance learning institution, merged with open distance learning (ODL) [46]. Under the new leadership, UNISA changed to an open-distance e-learning (ODeL) institution [46]. Lately, UNISA has a new identity – that of an institution of comprehensive open distance e-learning (CODeL) ([47]. Table 1 outlines the shifting of institutional identity in the 21st century.

Table 1. The revolving UNISA identity

Year	2001-2010	2011-2020	2021-2022
Identity	ODL	ODeL	CODeL
Leadership	Prof Barney Pityana	Prof Mandla Makhanya	Prof Puleng LenkaBula

UNISA has moved from its identity as an open distance learning (ODL) institution. The ODL mode offered instruction at a distance, with little face-to-face interaction between lecturers and students. ODL instruction utilized a variety of techniques, including in-person instruction, online media, discussion courses, tutorials, and other blended forms of instruction [48]. Blended learning essentially combines traditional and online education [49]. The ODL mode may have drawn large numbers of students because it was regarded as the best option for persons who were already employed to continue their education, as well as for those who had just finished secondary school [50]. In this way, the implementation of the ODL model at UNISA resolved the problem of limited access to higher education [51].

The change from ODL to ODeL involves a methodology that fully utilises online resources for learning. The ODeL business model assumes that contemporary electronic technology and other digital resources can assist all students in learning in the best possible way [52]. However, not all students in developing nations, such as South Africa, have access to the equipment, programs, and apps required for online learning [53]. Lecturers at distance education institutions, like UNISA, are concerned about their geographically scattered students' lack of connectivity [54] and, therefore, there are only limited digital materials that they can incorporate into their teaching. In order to fill this identified gap, UNISA is committed to providing its students and staff members with the relevant ICT infrastructure, which plays a significant role in a digital forum [46]. Lately, UNISA has proposed to change to a CODeL [55]. It is a multifaceted idea designed to reduce the gaps in communication between students and

institutions, academics, course materials, and peers, as well as the gaps in time, space, economics, society, and communication [47]. The reconceptualization of CODeL focuses on removing barriers to accessing learning, focusing on the flexibility of learning, student-centeredness, supporting students, and constructing learning programmes with the expectation that students can succeed [56]. What constitutes CODeL as relevant and advanced are open, distance, flexible, technology-enhanced and eLearning practices in the following possible research areas "Changing Roles and Capacity Development in CODeL; Digital Literacies; Mobile Learning; Massive Open Online Courses (MOOC); Open Educational Resources (OER); Online Assessments; Other Alternative Assessment Practices; CODeL Student Support; Designing for Accessibility to Support Students with Disabilities; CODeL Policy Formulation" (57:4). In pursuit of the university strategy and 2030 vision and by embracing the CODeL approach, which harnesses 4IR technology, UNISA may become a fit-for-purpose, future-fit and tech-fit organization [57].

4 Theoretical underpinning

This study opted for Roger's diffusion of innovations theory. In studying users' adoption of innovative technologies, it is important to examine their artifact knowledge, prior knowledge, previous practices, innovations, and the norms of social systems [7, 8]. Opting for Roger's concepts such as knowledge (awareness), persuasion (interest and perceptions), decision (evaluation/benefit), implementation (trial), and confirmation (adoption) [7]. The use of technology in higher education and educational settings can be studied using diffusion innovation theory (7). Opting for such a framework helped to obtain the relevant results on shadow IT in the appropriation of OER. Additionally, this enabled the understanding of the processes of how humans interact with, make sense of, and appropriate the functions of an IT system in the context of the social practices of an organisation [9].

5 Methodology

This study employed a constructivist research methodology and a qualitative approach, with the case study (the CODeL institution) as the chosen research design. Because the initial participants were chosen from a diverse institution with eight colleges, 18 schools, and 70 departments, snowball sampling was used. The first step in reaching potential volunteers was to obtain ethical approval and permission to conduct the research. A total of 42 academics – consisting of Junior Lecturers (JL), Lecturers (L), Senior Lecturers (SL), and Professors (P) participated in the semi-structured interviews. Due to their flexibility, semi-structured interviews appear to be the most effective method for qualitative research. The interviews lasted for 25–60 minutes. One of the ways for collecting data in this study was document analysis. Documents, which included the OER plan, the Open Distance Learning Policy, and the UNISA Annual Reports (2013 and 2019), were analysed as part of the triangulation of the existing data. In this study, the actual collection of artifact data was con-

sidered. The researcher used the OER library portals of the institutional repository to observe and make notes on created OER.

The data collection process was followed by the analysis of the data. A database specifically created for this study was used to handle and store all the studied data, which included transcribing, noting interesting elements, categorizing the complete data set, looking for themes, analysing links among themes, defining and identifying themes, and completing the analysis. NVIVO program received all created data from audio and Microsoft Word. After being made anonymous, the transcripts were coded in NVivo and analysed. After re-reading the interviews and the codes, NVIVO memos were created on various topics by returning to the individual interviews and further analysing the data. At this point, the researcher began to look for themes. The researcher reviewed all of the coding, themes and links between the primary themes and began redefining and renaming the final themes after identifying or combining concepts and completing the analysis. The research code of conduct and ethics were followed in the study. Following ethical guidelines is essential, including those relating to informed consent, confidentiality with regard to participants, sponsors and coworkers, the importance of the benefits of the study to participants over the hazards involved, and participants' requests that go above and beyond social standards [57]. Therefore, participants' identities were kept private in the presentation and discussion of the findings.

6 Findings

Table 2 presents the demographic characteristics of all participants involved in semi-structured interviews.

Table 2. Characteristics of participants

Gender:	**No.**	**Highest Qualification:**	**No.**	**Work experience (years):**	**No.**	**College**	**No.**	**Academics ranking:**	**No.**
Male	24	Honours	3	1 – 3	8	Accounting Sciences	3	Junior lecturer	3
Female	18	Masters	20	4 – 5	9	Agriculture and Environmental Sciences	5	Lecturer	20
Academic title:		PhD	19	6 – 10	15	Economics & Management Sciences	7	Senior lecturer	11
Mr	14			11 – 15	4	Education	4	Professor	8
Ms	10			16 – 20	5	Human Sciences	10		
Dr	10			21 – 25	0	Science Engineering & Technology	6		
Prof	8			26 – 30	1	Graduate Studies	3		
						Law	4		
Total participants = 42									

6.1 Knowledge and perceptions of OER

Although academic participants were knowledgeable and held various opinions about OER, the minority of the participants were not entirely certain about OER artifacts, which clarified some people's ideas about adopting OER. Not all academics were comfortable with the use of online resources, OER are Internet-based resources that generate course anxiety. Some academics expressed concern that not all teaching resources downloaded from the Internet were reliable and subject to peer review. The lack of subject specific OER was viewed as a challenge. The additional information and perspective characteristics that emerged from the academic job experience in a CODeL environment included the following:

> "*No*, *I just heard and experienced OER when I arrived here in a CODeL institution"* (Junior Lecturer 2).

Academics recognise any electronic or online resource that is pertinent for educational purposes as an OER. Several academics indicated that OER are educational resources that are accessible online and can be found in journal articles, digital textbooks, blogs, open sources, databases and library portals. These resources are helpful in meeting the demands of teaching and learning. CODeL academia also hinted at OER being easily available online resources that may be accessed at any time and from any location. The participants also made a veiled reference to the fact that, since the necessary resources were freely accessible in international digital domains, academics were no longer required to buy or recommend hard copy books. However, there are ongoing arguments, since some argued that OER and open educational materials were the same thing. The term "OER" refers to both open electronic resources and open educational resources, which can both be obtained online.

> *"I thought that open electronic resources and open educational resources are one thing and I didn't know any difference"* (Lecturer 5).

6.2 Implementation of OER

Academics participated in the development of OER and chose various OER implementation strategies. Academics began with basic responsibilities by creating their own programmes that may be used on smart devices that many students own. Mobile apps, podcasts and other platforms that made it simple to access OER were some of the specially created platforms. The developed platforms or apps were recognized as being easily accessible via smartphones, which was mentioned as a benefit, given how common smart device ownership was among academics and students.

> *"I developed a mobile App for practical teaching skills so it`s already there I had the pictures on it*" (Professor 2).

> *"It is important that we become techno-savvy and being techno-savvy becomes very easy for you to use the systems to use the OER systems to enhance teaching and learning"* (Lecturer 4).

Academics preferred to create apps and systems, because their students found them more convenient, in that they can access them wherever they are, including on trains, in restaurants, and in gyms. Therefore, they do not necessarily need desktop personal computers (PCs). Academic participants also suggested that file sizes and types should be kept to a minimum and should be more suited for OER. Some academics also favoured employing website builder programs to create distinct web platforms. Academics recommended CODeL building common platforms with content that is solely classified according to OER and organized by schools, colleges, departments and subject-specific areas as part of the implementation. In addition to the online platforms, they referred to the need for relevant or suitable systems and application software compatible with OER. Academics proposed that OER platforms should also cater for all OER-related to research and community engagement.

6.3 Shadow IT for the adoption of OER

In the adoption of OER, academics used a variety of technologies and apps, some of which were part of shadow IT. OER was largely accepted by academics rather than being developed. YouTube, other academic institution websites, and Open Educational Resources Universitas (OER Universitas) were the most commonly adopted platforms. The OER Foundation, an autonomous, non-profit organization that coordinates OERU, provides free online courses to students and academics all around the world [60]. Academics indicated that they chose OERU, because it offers a large collection of OER that are organized by topic area and are available to everyone. OERU purposes are considered to be relevant to increase access and reduce the cost of tertiary education for students around the globe – particularly those who do not qualify or who are excluded from enrolling at HEIs.

> *"I adopted OER from OERU and these resources were relevant to Computer Science"* (Senior Lecturer 9).

Besides OERU, academics adopted resources from YouTube for OER. One of the main reasons for adopting YouTube was its usability and user-friendliness. Academics claimed that YouTube attracted numerous viewers, besides their students and, because it plays a role in open access, it was regarded as a relevant platform for OER. It was easy to adopt video content from YouTube, it does not require any registration or subscription processes prior to the adoption of resources. They considered YouTube as being open and promoting open access and scholarship. Some academics opined that the CODeL institution was against the idea of academics hosting educational content on YouTube – because of copyright and intellectual property of the institution.

> *"The University has the policy that we are not allowed to put or adopt material from YouTube"* (FG2_Participant 2).

Furthermore, academics recommended that institutions should consider the use of artificial intelligence (AI) for the adoption OER. In the advent of the Fourth Industrial Revolution (4IR) era, academics felt that they should be strategic and recommended

machine learning to assist in the adoption of OER. They assumed that, when institutions started investing in robotics for OER, it might speed up the process. They felt that human interaction can be a misleading factor in the process of searching for OER, whereas AI is more accurate.

> *"If we integrate the robotics, into the facilitation of OER … I mean robotics can help, robots can lead you to the exact information you are looking for"* (Lecturer 6).

6.4 Shadow IT for dissemination of OER

Shadow IT offers potential growth in the dissemination of OER. Academia used both official IT and shadow IT. The most used systems for the dissemination of OER are social media, interactive platforms, and cloud storage. Social media were mostly used in the dissemination of OER to students for teaching and learning purposes. Academics preferred social media because of their usability, convenience, functions, and the freedom to upload and store content. Additionally, social media are more affordable than any other software programs The academic participants used a variety of social media applications, such as Facebook, WhatsApp, YouTube, blogs, ResearchGate and LinkedIn. Facebook has gained popularity for OER, as evidenced by the high numbers of academics who use it for their content. Other participants considered podcast programmes, which allowed the production of audio lessons related to their module content. Academics mentioned that the most used social media were user-friendly and students with their own smartphones can easily access or utilise such platforms. Some of the academics confirmed that there was no need for social media classes or training, because, regardless of the level of education, anyone can explore and teach himself/herself. Social media were considered instrumental in the use, dissemination and promotion of OER because of their simple, recognisable graphics interface and the little hassle when uploading and downloading OER content.

> *"ODeL* [institution] *will make effective use of educational and social technologies in learning programmes in appropriate and innovative ways that improve the quality of teaching and learning"* (ODeL Policy).

The study recognises an enormous confusion between the official institutional ICT and shadow IT. Some academics used Behance and Weebly and considered them shadow IT. These platforms enabled them to personalize and store teaching subjects and other academic contributions. Academics used Weebly for creating their OER websites and blogs related to their OER activities. They revealed that opting for and considering such platforms could play a role in the development, distribution and sharing of OER. However, such platforms were not authorised by UNISA, which might demonstrate the lack of a classification of institutional officialised ICT and they categorised the as shadow IT.

> *"ICT systems, including but not limited to computing equipment, software, operating systems, storage media and network accounts that provide access*

to electronic mail (e-mail) and the internet, are the property of UNISA" (ICT Acceptable Use Policy, 2020).

There are several new interventions and software developments occurring, which are either developed by UNISA employees or any other academics. Such application software is useful, although not licensed by UNISA. The Behance and Weebly were installed on UNISA computers and used by academics to benefit the institution during the dissemination of OER. However, the same policy states:

"Proprietary software licensed to UNISA shall not be installed on UNISA employees' and third parties' personal computers" (ICT Acceptable Use Policy, 2020).

7 Discussion

7.1 Knowledge and perceptions influence shadow IT

The users' knowledge and perceptions are the contributing factors to the utilisation of shadow IT in an organisation. In the current digital era, end-users (academics) have an expanding number of IT options, and recent data suggest that these end-users are increasingly using shadow IT in support of their tuition [58].

The research findings showed that experienced and knowledgeable users were the main users of shadow IT. IT users are increasingly experienced in adapting technologies to their needs, resulting in the widespread use of shadow IT [59]. The ICT literate users can select the most suitable systems and software for the appropriation of OER, which is an indication of experienced users having positive attitudes toward the adoption of shadow IT for the appropriation of artifacts. Shadow IT users are positively related to individual performance and produce better results in an organisation [62]. They are creative, innovative, efficient and opt for new platforms. Educational institutions integrate information technologies and pedagogical software tools into the educational process, so as to improve educational and methodological support [60]. Additionally, knowledgeable users contribute to collaboration and timely online visibility in a global sphere [36].

The inexperienced users do not contribute to the use of shadow IT. These types of users are skeptical about exploring more applications and software from the Internet for OER purposes. Shadow IT may be inadequately inspected, due to the adopter's lack of experience or knowledge of sound security practices, which are often inadequately maintained, thereby resulting in vulnerabilities [2]. They tend to rely on the prescribed ICT. It is possible that they avoid Internet resources, because they assume that they are not credible. This is elicited from the fact that shadow IT systems and software are often retrieved from the Internet. However, the transformation has taken place in the education sector. The workforce has a strong propensity to change because of the development of digital life, the Internet of Things (IoT), robotics, AI and automation technologies. Therefore, education systems globally must implement their educational transformation in accordance with the 4IR [2;61]. In the advent of OER, the study proposes that users' knowledge and perceptions are crucial in determining

the status of engagement and utilisation of shadow IT at a higher education institution.

7.2 Implementation as perpetrator of shadow IT

The actual implementation of OER takes place at a CODeL. Academics are innovative during the development of OER. OER can be considered as shadow education, which is a private extracurricular activity outside of the traditional educational system, aiming at facilitating students' success and providing access to superior educational materials [6]. In so doing, it requires academics to be ICT-skilled. As information technology advances, it is necessary to identify and use the right technologies, so that organisations may effectively compete in the market by utilising accurate and real-time efficiency [64]).

There is a new trend in the advent of OER that involves academics venturing into development, rather than adoption. OER should be developed with little effort for easy integration and customization within teachers' pedagogical processes by relying on ICT to customize learning content [19]. Research findings and literature concur that academics are capable of appropriating ICT and resources to advance tuition and learning. The creativity of academics demonstrates dedication to the provision of tuition in an e-learning context.

The findings postulate the significance of implementation because it enables the creation of relevant resources suitable for the subject and specific to the module content. The implementation of OER creates more opportunities for faculty to customise and redevelop their own platform that is user-friendly for their students in their context [62]. The literature affirms that the implementation is advantageous, however, it perpetrates the usage of shadow IT [63]. This further signifies that academics are considerate of their students and their own institutions. However, the entire process of implementation and innovation seems to lack the observation of shadow IT: only the benefits of OER in the institution are prioritised. This allows the proposition that the innovative users contribute to the advancement of OER when shadow IT is appropriated and academics must not be limited to particular systems. Instead, they deserve better recognition and acknowledgment.

7.3 Shadow IT for adoption and dissemination

The findings reveal that shadow IT has been appropriated for the adoption and dissemination of OER. In the era of rapid development of mobile Internet, video have become a popular communication method for the audience [64]. In the diverse and evolving digital infrastructure, academics, audiences, institutions, and other stakeholders create, and maintain a broad landscape of platforms to disseminate knowledge [41] by using different types of ICTs, including shadow IT. Academics sometimes avoid the use of existing institutional ICT systems when adopting, developing, and disseminating OER. For example, they can use different online platforms. Academics may also rely on shadow IT – i.e. any hardware or software in an enterprise that is not supported by the central IT Department of the domain [4].

There is a concurrence between the literature and research findings, because academics tend to rely on various platforms to adopt relevant OER. In this study, shadow IT was found to be useful in the dissemination of OER, although this raised the alarm in terms of a discrepancy between the ICT policy, tuition policy and the emergence of OER. Most cited ICT and tuition policies do not articulate OER-related issues thoroughly, although there is an OER strategy that governs the adoption and development of OER. The strategy and policies seem to hinder innovation in the advancement and dissemination of OER. Therefore, the study proposes that the revision and realignment of the institutional policies. The integration of dual virtual structure policies for education contributes to the elimination of the recurring OER problems in academia [13]. Therefore, the study proposes that the institution requires to take cognisance of ICT and its usage policies and strategies to accommodate shadow IT for adoption and development of OER to be aligned with the institutional rules and regulations.

8 Conclusion and recommendations

The study investigated the way in which shadow IT is used in the advent of OER, particularly in a CODeL institution. To answer this question, the study opted for phases or concepts in the innovation theory. This theory supported the identification of various factors or causality of shadow IT in the appropriation of OER. Investigating the usage of shadow IT when dealing with OER was necessary, to acquire a deeper understanding of artifact knowledge and perceptions; implementation of artifacts; and how artifacts are adopted and disseminated. Gathering knowledge and perceptions was crucial for the status and the future of the users involved in the application of shadow IT. Knowledge and positive perceptions are the indicators that academics are involved in the utilisation of shadow IT than institutional IT when dealing with OER. The study established that, while developing, adopting and disseminating OER, academics primarily rely on shadow IT. The major suggestion would be that institutions realign and revise their ICT and tuition policies and their OER strategies to include shadow IT in support of the ongoing growth and innovation of OER. The research results of the study indicated that there are numerous gaps in the literature. This implies that future research may examine ICT, OER and tuition policies for all 26 public universities in South Africa, to learn about the current approaches of incorporating shadow IT in the age of the Fourth Industrial Revolution.

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The Role of Well-being and Engagement on Software Team Performance

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Abstract. The software project teams are suffering from poor team performance, that leads to a higher failure rate of software projects. The poor performance of the software project team is the result of the poor job performance by the members of the software project team. The poor performance job performance by the members of the software project team is through poor well-being and lack of work engagement of the members of the software project team. The main aim of this research study was to evaluate the influence of well-being and work engagement of the members of the software project team on their job performance which leads to success of software projects. The researcher conducted a quantitative research study using a survey approach and quantitative data was collected using an online questionnaire. The researcher performed Partial Least Squares Structural Equation Modelling (PLS-SEM) using Smart PLS 4,0. This was done to validate the hypothesis of the research study. The results show that well-being and work engagement have positive significance on the performance of the members of the software project team. The job performance leads to good software project team performance. The software project team needs to have good team performance to ensure the success of software projects. There is a need to understand how different well-being contributes to the job performance of the members of the software project team and to increase performance of software project.

Keywords: Software Success, Team Performance, Individual performance, Job Performance, Well-being, Work Engagement.

1 Introduction

The software project teams have the responsibility and duty of ensuring the success of software projects [1]. The members of the software project team are the ones that perform all the tasks that are required to ensure the success of the software project. The members of the software project team are the main source of addressing the failure of software projects which is at alarming rate [1] [2]. The members of the software project team need to have good performance for the software project team to meet its main objective which is success of software project. The high performing software project team ensures all the tasks are performed to the required quality

standard including delivering them on-time with the correct out or functionality [2][3].

The soft competencies are more important and essential to the members of software project team because soft competencies complement the technical competencies. Soft competencies make the members of software project team to be productive and competitive in their respective roles [2][4]. Soft competencies complement the technical competencies which create a balance on the competencies that are required by the members of the software project team when performing tasks. The soft competencies have a major role in ensuring the software project team and its members are productive [2].

The soft competencies are not given much attention within the software project environment and have led to poor performance of software project teams [4]. The major source of failure of software projects is soft issues. Most critical failure factor of software projects are soft issues which are constitute a total of 80 percent of critical failure factors [5]. Therefore, this indicates the soft competencies had been the source of failure of software project, but the emphasis was given to the technical issues such as introduction of new methodologies such and improvement of technologies [4].

Members of software projects have poor performance because of stress, and burnout which results in poor team performance. Poor performance of the software project teams, and its members result in the higher failure of software projects. The stress and the burnout of the members of the software project continue to contribute to the current challenge of the higher failure rate of software projects. The higher failure rate of software projects made different organizations not being competitive in the current era of fourth industrial revolution which rely heavily on technology which is one of the primary driving factors on the success organizations [1][3]

The members of the software project team need to overcome the burnout and stress for them to have good job performance [3]. The members of the software project team require soft competencies for them to have good job performance. There are two soft issues that have become more important and relevant in the current era namely well-being and work engagement. The well-being of the members of software project is more relevant and important in the current era where most of the member of software project team are experiencing the mental issues such stress and burnout which are more dominant when it comes to the health issues to the working class [6][7].

The main aim of this study was to evaluate the influence of well-being and engagement of the members of software project on the success of software projects. The researcher started by outlining the theoretical background, research design and methodology, data analysis followed by the discussion of the results. The researcher concluded everything by outlining the conclusion which included the future research and limitation of the research study.

2 Theoretical Background of Research Study

2.1 Software Project Success

The success of a software project is the main goal for any software project team [5]. The success of the software projects is given much attention because of the higher failure rate of software project that had been in existence for a long period of time. The failure of software projects had been in existence for more than six decades to an extent that it had been declared as an international crisis [1][5]. Despite all the attention had been given to the success software projects with different approaches such as Agile methodology, but the failure of software project still a challenge [3][5].

The software project team has the responsibility and obligation of ensuring the success of the software project. The software project team performs all the tasks collectively to ensure the success of the software project [2][8]. Although it is the responsibility of the software project team, it is not the software project team that benefits from the success of software project team instead there are different stakeholders that benefit from the success of software project such as the primary customer, organization, and senior management of the organization [9]. The organization and senior management benefit through achieving the main goal of commissioning the software project such as improving the functioning of the organization and achieving strategic goals [10].

The achievement of the success of software project is an enormous challenge for the software project team and its members [5]. The challenge results from the number of issues such as financial resources that are being invested in, and the reason for commissioning the software project [10]. Software projects are more challenging to software project team because changes that are being introduced on software project especially on the scope of software project that result in scope creep. Scope creep creates conflicts among members of software project team and other stakeholders [11].

The software project team needs to have good team performance which can lead to high performing team ensure the success of software project [3]. The good performing software project team can perform all the tasks to the required quality standard and completing the tasks on time which puts software project in good position to ensure the success of software project [1][9]. This indicates the software project team needs to have good team performance.

2.2 Team Performance

The software project team performance is one of the key issues that has grabbed the attention of different researchers in the current era [3][4][12]. Software project team performance is more important because software projects are being conducted by software project teams that bring together different expertise and knowledge that is required to ensure the success of software project. The software project team has the duty and responsibility of performing all the tasks within the software project that builds towards the final software solution that result in the success of software project

[12]. Software project team performance further indicates the software project team function cohesively towards achieving the main goal of software project team [10].

Software project team performance consists of two elements namely efficiency and effectiveness [13]. Effectiveness is the degree to which the software project team attains the quality standards on the outcome of software process especially on the duties conducted by software project team. Effectiveness focuses on the quality elements of the success of software project including quality of software solution [14]. Effectiveness enables the software project team to develop a software solution that address all the requirements of the primary customer especially the functionality of software solution and ensure the software solution is free from any bugs which affect the quality of software solution [13][14].

Efficiency is the degree in which the software project team uses allocated resources i.e., financial resources, human resources and time that is allocated to complete the software project [14]. The main objective of efficiency in software project team performance is about the software project team achieving the objectives of the software project using allocated resources. Efficiency of software project team performance enables the software project team to meet success elements namely time, scope, and budget which formulate triple constraints [13]. Therefore, effectiveness focuses on quality and efficiency focuses on triple constraints of success criterions of software projects.

The aim of any senior management is to have a high performing software project team [3][13]. The high performing teams have good collaboration capability, mix of technical and soft competencies, problem solving skills and interpersonal skills. These elements make the software project team perform its tasks accordingly [3]. The high performing software project team can perform their tasks to the required quality standard and complete the tasks within allocated time [14]. Therefore, it is important for a software project team to be a high performing software project team [3].

Software project team performance enables software project team to have productivity, flexibility, and business alignment [14]. Productivity makes the software project team perform their tasks to the required standard which enables the software project team to deliver the software project successfully [3]. Flexibility makes the software project team find solutions to the challenges that are experienced during the lifespan of software project. This enables the software project team to ensure the success of the software project. Business alignment is important because software projects are commissioned based on business needs which is one of the success criteria for software projects [14]. The following hypothesis was developed:

H_1: The performance of software project has positive and significant relationship with the success of software project.

2.3 Job Performance

The job performance of the members of the software project team needs to be of a good standard for the entire software project team to be a high performing team [3][15]. The job performance of the members of the software project team is primary

building block towards team performance [16] because the members of the software project team are the ones that use their knowledge and expertise to perform tasks within software projects that lead to the success of software project. The members of the software project team are important elements for any software project because without members of the software project team nothing can be done within software project [15].

Job performance of the members is influenced by two elements which are personal qualities and the working environment [17][18]. Personal qualities consist of their skills, knowledge, capacity, competencies, and knowledge [18]. Personal qualities are the important elements and requirements for the member of software project to perform their tasks especially towards performing their tasks effectively and efficiently [17]. Personal qualities of the member of software team to have good job performance.

The work environment of the members of software project team has the elements of job expectations, performance feedback, tools of trade, the working environment, and the reward system [18][16]. The job expectation provides clarity on what the members of software project team need to do as part of their job roles within software project team [19]. The feedback performance provides the members of the software project team with where to improve or the areas of their performance that are not of a good standard. This results in the members of the software project team improving on the job performance. The members of the software project who have the adequate and correct tools that are required to perform their work to the required standard [20].

The members of the software project team that work in a healthy environment are productive. The work environment has a huge influence on the job performance of the members of the software project. If the environment of the members software project is toxic, it results in the members being stressed and suffering from burnout which results in the members of software project underperforming which result in them having poor job performance [16]. The toxic environment further affects the well-being of the members of the software project team having different mental health issues that are currently on the rise [21]. The reward system for the members of the software project team is one of the motivations that leads to the members of the project team to be productive and having good job performance [22]. The following hypothesis had been developed:

H_2: The job performance of the members of the software project team has a positive and significant relation with the performance of the entire software project team.

2.4 Team Member Engagement

Team member engagement basically is drawn from the employee engagement or work engagement and these terms that are being used interchangeably. Team member engagement is the degree of the member of software project team show the preference in their tasks allocated to them especially creating the connection between self and the job. This results in the increased performance of the member of software project team through the emotional, cognitive, and behavioral energies towards achieving the ob-

jectives of software project [23]. The members of software project team with engagement have high levels of energy and mental resilience while performing their tasks. This makes the members of the software project team go the extra mile to ensure their tasks are performed properly to the required quality standard [24].

The members of the software project team with engagement find the greater meaning on the type of work they are doing including performing the tasks that are allocated to them. These members find joy in performing their tasks within software project team which makes such members perform their tasks to the required quality standards including delivering tasks on time [25]. The members of the software project team with engagement are always open to learning new things and to grow as individuals [24]. The learning process makes these members gather and gain more accurate knowledge and expertise which makes such members are productive [24]. The members of the software project team that are seeking growth which makes them to be productive and competent to indicate readiness for a higher position and more responsibilities [23].

The members of software project team with engagement go extra mile in performing their tasks that are allocated to them [23]. This is done by the members of the software project team by putting more effort into performing the tasks to the required quality standard. It includes the members of the software project team by being enthusiastic about the job within the software project team. This results in the members of the software project team having greater job performance. The engaged members of the software project use their strength and capabilities to yield positive results to them and the software project team. These members further work hard to ensure that they are productive to ensure that they have good job performance [24]. Therefore, the members of software project team with engagement lead to good job performance [25]. The following hypothesis was developed:

H_3: Engagement of the member of software project team has positive and significant relationship with the job performance of the member of software project team.

2.5 Team Member Well-being

The well-being of the members of the software project team has become more significant and important because software project team members are experiencing a lot of challenges in the form of burnout and stress [21]. The stress results in the members of the software project team experiencing burnout which leads to poor performance of the members of the software project team [2]. The poor job performance of the members of the software project results in poor performance of the entire software project team which leads to the failure of software projects [3].

The members of the software project team with good well-being have greater productivity, turnover, less absenteeism, and less burnout [26][3]. The productivity of the members of the software project team indicates that the members of the software project team can deliver and perform all the tasks that have been allocated to them on time. The members cannot only perform the tasks, instead they perform quality work and deliver their tasks on time [23]. The members of the software project team with

good well-being are less absent from work, which indicates that they are always available to perform their tasks as compared to those who have poor well-being [21].

The members of software project with good well-being are always thriving at their work [27], have good life satisfaction [28] and good social support [27] especially with their life in general and psychologically [29]. The members of the software project team that are thriving in their work includes members being productive and performing the tasks accordingly to ensure that software project teams meet the milestones and their deadlines [27]. The good life satisfaction leads to the members of software project team being happy and satisfied with their job which leads to them performing their jobs accordingly. Life satisfied members of software project team are always ready to help other members by sharing their knowledge and collaborating with other members of software project team [28].

The psychological well-being of the members of the software project team is important because it makes the members have a good relationship with other members of the software project team [28]. Positive and quality relations among the members of the software project team enable these members to collaborate and share knowledge [26]. Collaboration is one of the most important elements that enable the entire software project team and its members to be productive [3]. Software projects are knowledge intensive in nature whereby it is impossible for members of software project team to perform tasks within software project without knowledge [30]. Knowledge further has positive influence the performance of the members of software project team [28]. Therefore, the following hypothesis was developed:

H_4: The wellbeing of the members of the software project team has a positive and significant relationship with the job performance of the members of the software project team.

H5: The wellbeing of the members of the software project team has a positive and significant relationship with the engagement of the members of the software project team.

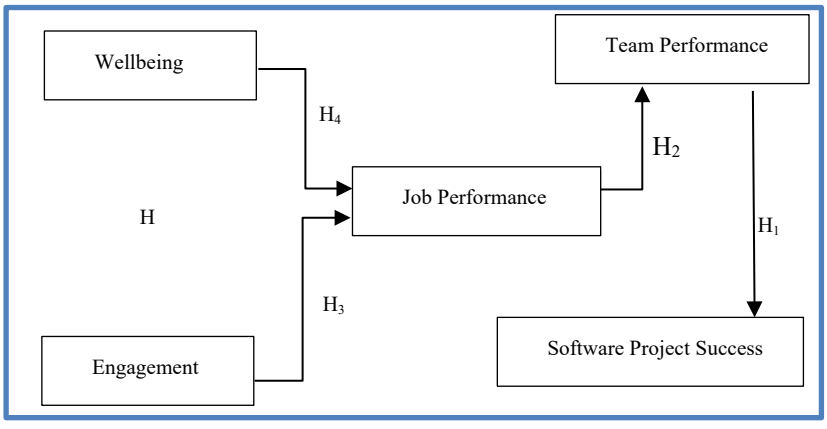

Fig. 1. Conceptual Framework of the research study

3 Research Design and Methodology

The researcher conducted quantitative research study because of the nature of the research study, especially the objective [31]. This research was about the validation of the hypothesis as depicted in figure 1. The nature of this research study was cause and effect research study [32]. The researcher used a survey approach and quantitative data was collected using the online structured questionnaire because it was cheap to use it [31]. The quantitative enabled the researcher to validate or test the hypothesis [31][32].

3.1 Instrument Development

The questionnaire was developed using the existing literature, especially the constructs. This was done to ensure the validity and reliability in this research study. Validity and reliability were important because contributed to the quality of the results that were generated in this research study [31]. The details of the constructs were further discussed during the measures in this research study. The questionnaire consisted of Likert scale items that were measured using 7-point Likert scale whereby 1 represented strongly disagree while 7 represented strongly agree.

3.2 Data Collection

The researcher collected quantitative data from the respondents of the research study using a structured questionnaire and the researcher was able to collect large amount quantitative data. The respondents of the research study were invited through email which included the information about the research, the rights of the respondents of the research study and the link to access the questionnaire of the research. The researcher collected a total of 226 responses which were sufficient for the type of data analysis that was performed in research study [33].

3.3 Sampling and Procedures

It was important for the researcher to collect the quantitative data from the correct and accurate sample to ensure the results were accurate and reliable [34]. The sample of the research study were individuals that were working within software project holding different roles. The targeted roles for this research study include business analysts, project manager, scrum master, quality assurers, software developers, senior managers, and team leaders. The details of the sample, especially the summary of the sample, were depicted in table 1.

Table 1. Sample Profile

Category	Options	Number	Percentages
Gender	Female	78	34.5%
	Male	148	65,5%
Age	18 – 30 years	47	20,8%
	31 – 40 years	109	48,2%
	41 – 50 years	58	25,8%
	➢ 50 years	12	5,3%
Number of Years of Experience	1 – 10 years	43	18,6%
	11 – 20 years	83	36,2%
	20 – 40 years	92	40,7%
	More than 40 years	09	4%
Industries	Banking	62	26,5%
	Consulting	73	32,3%
	Information Technology	47	20,8%
	Insurance	27	12%
	Health	17	7,5%
Qualification	Certificate	13	5,8%
	College Diploma	29	12,8%
	Bachelor's Degree	142	62,8%
	Postgraduate Qualification	42	18,6%
Number of Software Projects	1 – 20 Projects	87	38,5%
	20 – 40 Project	104	46%
	40+ Projects	35	15,5%

3.4 Measures

Software project success is all about the software project team completing the software project within an allocated time, with all the required functionality (scope) and within the allocated financial resources. Success of software project includes making the primary customer happy by making sure the customer is satisfied, meeting the business goals, and delivering the quality deliverables [35]. Software project success was measured using 6 Likert scale items which were extracted [36]. The lowest factor loading was 0,868 while the highest factor loading was 0,907. Composite Reliability was 0,961, which was above the minimum value of 0,5. The Cronbach Alpha for reliability for software project success was 0,951 which is above the minimum value of 0,5 [33].

Software project team performance is the degree in which software project team perform the tasks effectively and efficiently. Software project team performance was measured using 8 items which were extracted from [37]. The lowest factor loading

was 0,684 and the highest factor loading was 0,935. Composite Reliability was 0,970. The Cronbach Alpha for reliability for software project team performance was 0,962.

Job performance is a behavioral, incidental, multifaceted, and measurable in nature and it takes into consideration the collection of intermittent incidents which the member of software project team complete over time allocated by software project team [38]. Job performance was measured using 6 items that were extracted from [38]. The lowest factor loading was 0,848 and highest factor loading was 0,934. Composite Reliability was 0,970. The Cronbach Alpha for reliability for job performance was 0,962.

Software project team member engagement is the level of commitment and involvement of the member of software project team towards their work especially performing their duties and towards the entire software project team achieving its goals [39]. Engagement was measured using 6 Likert scale items which were adapted from [40]. The lowest factor loading was 0,804 and the highest factor loading was 0,935. Composite Reliability was 0,962. Cronbach Alpha for reliability of engagement was 0,953.

Well-being is the evaluation of software project team members' life, their overall quality of the software project team member's experience and functioning as the member of software project team which includes the life satisfaction [41]. Well-being was measured using 5 Likert scale items which were adapted from [42] The lowest factor loading was 0,897 while the highest factor loading was 0,970. Composite Reliability was 0,970. Cronbach Alpha for reliability of engagement was 0,958.

3.5 Ethical Consideration

The researcher needed to adhere to ethics while conducting this research study. Ethics exist in this research study to protect the respondents and/or participants of the research study from any harm which can be in any form under the pretense of conducting research or advancing knowledge [34]. The researcher applied for ethical clearance from the school ethics board, and it was granted. The respondents of the research study gave consent prior to completing the questionnaire. The participation in this research study was voluntary. The researcher further ensured the anonymity of the respondents.

4 Data Analysis

The researcher conducted quantitative data analysis. The quantitative data analysis was used in this research study to validate the hypothesis. The researcher performed Partial Least Squares Structural Equation Modelling (PLS-SEM) using Smart PLS 4,0. PLS-SEM was used to test the measurement of structural models because PLS-SEM has a capability of predicting power to analyze complicated models for high order constructs [33]. PLS-SEM further caters the assumptions such as normality, linearity, and multi-collinearity for both parametric and nonparametric data [43].

4.1 Reliability and Validity Analysis

The measurement model, especially the quality, was assessed to establish the reliability and validity of the constructs that were used in this research study. The validity and reliability were important. The researcher started by ensuring the factor loadings of all items have a value that was greater than 0,5 which is the minimum value [33]. The reliability of the constructs was measured using Cronbach Alpha (α), composite reliability (rho_c) and the Average Variance Extracted (AVE). The Cronbach's Alpha values were greater than 0,7 which was acceptable minimum value [43]. This indicates all the constructs in this research study had good reliability based on Cronbach's Alpha criteria. All the constructs had rho_a values there were above the minimum value of 0,5. The rho_c of constructs needed to have a minimum of 0,5 and all the constructs had values greater than the minimum value [43]. The CR values of constructs needed to have the minimum of 0,5 and all the constructs were above the minimum of CR [43]. The convergent validity was evaluated using AVE which needed to have a minimum value of 0,5 [33]. All the constructs had values that were greater than the minimum value.

Table 2. Reliability and Validity of Constructs

Construct	Items	Loading	Alpha	RHO_A	CR	AVE
Success	Succ_1	0,868	0,951	0,955	0,961	0,804
	Succ_2	0,904				
	Succ_3	0,905				
	Succ_4	0,907				
	Succ_5	0,897				
	Succ_6	0,898				
Team Performance	TP_1	0,804	0,962	0,964	0,970	0,823
	TP_2	0,928				
	TP_3	0,958				
	TP_4	0,684				
	TP_5	0,962				
	TP_6	0,935				
	TP_7	0,935				
	TP_8	0,918				
Job Performance	JP_1	0,927	0,953	0,968	0,962	0,808
	JP_2	0,867				
	JP_3	0,923				
	JP_4	0,934				
	JP_5	0,879				
	JP_6	0,848				

Well-being	WB_1	0,960	0,958	0,966	0,970	0,889
	WB_2	0,970				
	WB_3	0,943				
	WB_4	0,897				
Engagement	Eng_1	0,898	0,899	0,923	0,928	0,764
	Eng_2	0,874				
	Eng_3	0,804				
	Eng_4	0,916				

4.2 Structural Model: Hypotheses Testing

The structural model reflected the paths that were presented by the hypothesis. The structural model for the conceptual framework for this research study was assessed using R^2 and Q^2. R^2 is the statistics that represents the variance in the endogenous variable explained by the exogeneous variable. The R^2 value of 0,75 represents substantial explanation, while 0,50 represents moderate explanation and 0,25 represents weak explanation by the exogenous variable [33]. The lowest R^2 was for job performance which was 0,130 and the highest R^2 was for well-being which was 0,445.

Q^2 is a predictive relevance which measures whether the model has a predictive relevance. Q^2 is used to establish the predictive relevance of endogenous variables in a model [33]. The Q^2 value that is greater than zero indicates the Q^2 has the predictive relevance and the constructed is well constructed [43]. The highest predictive relevance was 0, 448 for well-being and the lowest Q^2 was for job performance which was 0,130. The Q^2 and R^2 were summarized in table 3.

Table 3. Sample Profile

Endogenous Variable	**Q^2**	**R^2**
Engagement	0,237	0,230
Job Performance	0,130	0,320
Team Performance	0,217	0,200
Success	0,297	0,242
Wellbeing	0,448	0,445

The researcher further performed the assessment of Goodness of Fit by testing the hypotheses. The researcher tested the strength, significance, and direction of the relationship. The researcher used path coefficient (β), *t*-value, and *p*-value. The β is expressing the magnitude and the direction between the two constructs. The *t*-value and *p*-value determine the significance level of the relationship between the constructs. The *t*-value needs to be greater than 1,64 and *p*-value needs to be less than 0,05 for the relationship to be considered significant [33].

The first relationship that was evaluated was between team performance and success which was positive and significant (*β = 0,501; t = 5,541; p = 0,000*). Therefore,

H_1 was supported. The second relationship was job performance and team performance. The relationship was positive and significant (*β = 0,707; t = 8,375; p = 0,000*). Therefore, H_2 was supported. The third relationship was between engagement and job performance which was positive and significant (*β = 0,381; t = 1,879; p = 0,011*). Therefore, H_3 was supported. The third relationship was between well-being and job performance which was positive and significant (*β = 0,590; t = 3,641; p = 0,004*). Therefore, H_4 was supported. The last relationship that was tested in this research study was between well-being and engagement which was positive and significant (*β = 0,669; t = 14,915; p = 0,000*). Therefore, H_5 was supported. Therefore, all the relationships that were developed in this research study were supported. This indicates all the hypothesis were supported in this research study.

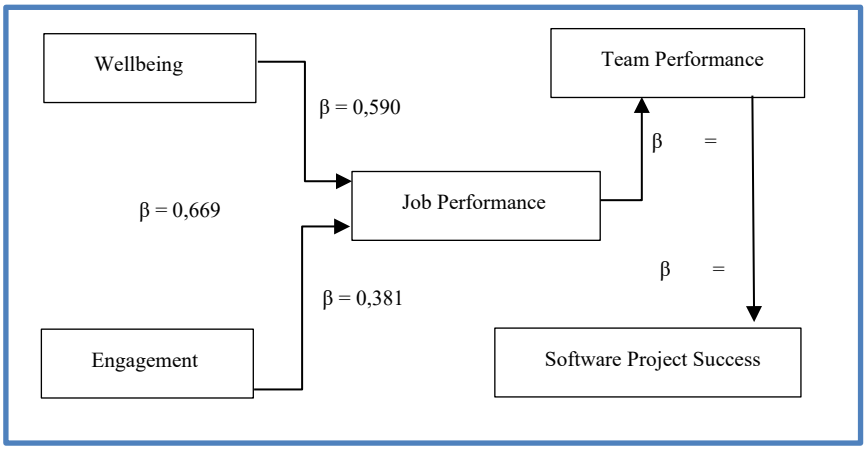

Fig.2. Validated Conceptual Framework

The first relationship that was evaluated was between team performance and success which was positive and significant (*β = 0,501; t = 5,541; p = 0,000*). Therefore, H_1 was supported. The second relationship was job performance and team performance. The relationship was positive and significant (*β = 0,707; t = 8,375; p = 0,000*). Therefore, H_2 was supported. The third relationship was between engagement and job performance which was positive and significant (*β = 0,381; t = 1,879; p = 0,011*). Therefore, H_3 was supported. The third relationship was between well-being and job performance which was positive and significant (*β = 0,590; t = 3,641; p = 0,004*). Therefore, H_4 was supported. The last relationship that was tested in this research study was between well-being and engagement which was positive and significant (*β = 0,669; t = 14,915; p = 0,000*). Therefore, H_5 was supported. Therefore, all the relationships that were developed in this research study were supported. This indicates all the hypothesis were supported in this research study.

5 Discussion of Results and Conclusion

The performance of the entire software project team is important towards the success of the software project. The performance of the entire software project team needs to be adequate for the software project to be delivered successfully and for software project team perform the tasks to the required standard [3][41]. The software project teams are formulated to execute software project need to be high performing software project team because high performing software project team ensures that it performs the tasks to the required standard which is required to ensure the success of software projects [3].

The job performance of the members contributes significantly to team performance. It is more important and imperative for the members of the software project team to have good job performance which leads to good software project team performance. The members of the software project team need to be high performing members for the software project team to be a high performing software project team. Therefore, it is important for the software project team performance to be formulated by the members of software project team that have accurate competencies and knowledge to ensure the members have good job performance.

The job performance of the members of the software project is influenced heavily by the well-being and engagement of the members of the software project team. The well-being of the members of the software project team has become more important in the software industry because software projects involve a lot of uncertainty, and they are challenging in nature [18][21]. Well-being also makes the members of software project team competitive which results in the members of software project team having good job performance. Well-being puts the members in a good state of mind.

The engagement of the members of software project makes the members of software project go extra mile in performing their tasks. Engagement of the members of software project team makes such members find joy in performing their tasks which makes them productive [25]. Engagement of members becomes one of the motivations for the members of the software project team to perform their work to the required standard and become the high performing members of software project team [24].

The engagement and the well-being of the members of the software project team result in the members of the software project team having good job performance. The job performance results in the members of the software project team performing their tasks to the required standard. That leads to good software project team performance which makes the software project team meet its objectives and goals which result in the success of software project. This indicates the soft issues contribute significantly to the performance of software project team and its members [24].

There is a need to conduct further research to identify the elements that are required to make the software project teams to be high performing teams that result in the success of the software project. There is also a need to understand the influence of different types of well-being on the performance of the members of the software project team. It is because the members of the software project team currently experience a high level of burnout which can be addressed by having good well-being of the

members of software project team. This study was also limited to few soft competencies which indicates there is a need for wider study that focus on more soft competencies. In conclusion, soft issues influence the performance of the members of the software project team and the members of the software project are essential in ensuring the success of software projects. In conclusion, well-being and work engagement improves the job performance of the members of software project team.

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A Blockchain-based Model for Securing Data Pipeline in a Heterogeneous Information System

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Abstract. In our digital world, access to personal and public data has become an item of concern, with challenging security and privacy aspects. Modern information systems are heterogeneous in nature and have an inherent security vulnerability, which is susceptible to data interception and data modification due to unsecured communication data pipelines between connected endpoints. This research article presents a blockchain-based model for securing data pipelines in a heterogeneous information system using an integrated multi-hazard early warning system (MHEWS) as a case study. The proposed model utilizes the inherent security features of blockchain technology to address the security and privacy concerns that arise in data pipelines. The model is designed to ensure data integrity, confidentiality, and authenticity in a decentralized manner. The model is implemented in a hybrid environment using a prototype implementation and simulation experiments with outcomes that demonstrate advantages over traditional approaches for a tamper-proof and immutable data pipeline for data authenticity and integrity using a confidential ledger.

Keywords: Data security, Heterogeneous systems, Blockchain, Data pipeline, Information system.

1 Introduction

Technological advancements have ushered in the Fourth Industrial Revolution (4IR) and the purported Fifth Industrial Revolution (5IR), with data becoming a critical asset in modern information systems. According to the statistics [7], [8], [9], 2.5 quintillion bytes of data are created each day, estimated to be worth around $77 billion by 2025 [1]. Data is the foundation of an information system, critical to its functioning, and plays a vital role in decision-making and strategic planning within an organization. In modern organisations, the ability to integrate data from diverse sources and systems is crucial for effective decision-making. From data collection to processing and analytics, maintaining data accuracy and security is of utmost importance throughout the entire process. Observations based on empirical evidence indicate that the exchange of data across multiple application endpoints exposes the data to a high risk of manipulation and destruction by malicious entities [2]. The attacks might have originated from any source, through a wide variety of attack mechanisms.

Typically, malicious hackers or state actors target accessible communication pathways of information systems – usually, data pipelines, which are not protected, using attacks such as man-in-the-middle (MITM) attacks, Cross Site Scripting (XSS), DNS Tunneling etc. The vulnerabilities of this critical communication channel have been the focus of researchers in information security [10], [26 - 27], [29]. Several countries have protection policies and fines for a data breach, urging the organization to provide rigorous mechanisms in place for data security. For example, South Africa promulgated the Protection of Personal Information Act, 2013 (Act 4 of 2013) ('POPIA') into law on 26 November 2013 and became fully enforceable on 1 July 2021 [11], with existing General Data Protection Regulation (GDPR) and other acts, resulting in, Equifax, a credit reporting agency agreeing to pay more than R10-billion to regulators to settle claims from a data breach [11]. Furthermore, if a company violates the General Data Protection Regulation (GDPR), the EU authorities may impose fines of up to 20 million euros or 4% of annual global revenue [5]. While these measures instigate the adoption of appropriate measures for adequate data security, they are not the solution.

Currently, traditional security mechanisms such as cryptographic techniques [3], [27] are frequently insufficient to maintain data integrity in this massive modern IT infrastructure. Recently, researchers have turned their attention to blockchain, being a distributed, incorruptible, and tamper-resistant ledger database. Blockchain has the potential to address the critical security vulnerability issues of information systems, particularly on data integrity and reliability or in applications that require extra trust guarantees [4]. Blockchain technology can be used to secure data by creating a decentralized, tamper-proof ledger of transactions. Each block in the chain contains a cryptographic hash of the previous block, creating a chain of trust that is difficult to alter. By storing data on a blockchain, it becomes much more difficult for hackers to tamper with or steal the data, as any changes would be immediately apparent and could be easily traced back to the source. Additionally, the decentralized nature of blockchain technology means that no single point of failure exists, which further increases the overall security of the data (Fig. 1). This research explores how the application of blockchain technology could be used to mitigate the security challenges confronting heterogeneous information systems using environmental monitoring systems as a case study.

Fig. 1. A decentralized Blockchain ledger [16].

The environmental monitoring domain generates lots of critical and sensitive data that influences policies and strategy and is a prominent sector for the application of blockchain technology for data security. For example, an attacker could compromise the readings of the monitoring system, providing scientists with misleading data, if this information informs policy changes or new technologies, it could thoroughly disrupt environmental efforts. In such a scenario, the application of blockchain technology can be the more favourable approach to attain security from recognized threats and mitigate against possible data compromise. Blockchain can also be used to secure heterogeneous data from environmental monitoring systems. By storing data on the blockchain, it can be ensured that the data is accurate and cannot be tampered with [15]. This can help to ensure that environmental monitoring systems are functioning properly. Blockchain technology secures data using advanced encryption methods, making it nearly impossible for unauthorized parties to access data stored on the blockchain on decentralized multiple nodes [12]. Decentralization is a core feature of blockchain technology [16], and it refers to the distribution of data and controls across a network of nodes, rather than having a central point of control – as a distributed ledger. Blockchain networks that are distributed among participants are called a consortium network. The consortium network gives each partner visibility into every transaction that occurs on the network. In a decentralized blockchain network, all nodes have a copy of the same data, containing an immutable ledger of all transactions [21]. Each node has the ability to validate and record transactions making it easy to track and trace any changes made to the data.

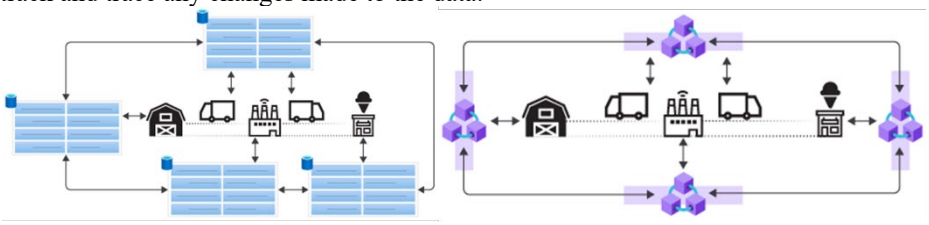

Fig. 11. Overview of a distributed database in comparison with a distributed ledger in blockchain [12], [16].

Blockchain makes use of smart contracts, which are self-executing contracts that can be programmed to automatically enforce data security protocols, such as terms of an agreement between data producer and data consumer written into lines of code. Smart contracts can be written and executed on blockchains like Ethereum [13]. These contracts are transparent and safe since they are created using code and kept on the blockchain. Smart contracts extend blockchain from data to code. One of the main advantages of smart contracts is their ability to automate and streamline procedures, eliminating the need for middlemen and resulting in time and cost savings. They also offer some amount of security and confidence due to the public availability and verifiability of the contract's code. In this area, numerous applications have been proposed, including hyper ledger fabric technology [14], Ethereum smart contracts [13], and other Blockchain as a Services (BaaS) [15, 16].

The objectives of this research study is to investigate how blockchain technology can be integrated with existing legacy and modern information systems. The main contributions of this paper are as follows:

- It proposes a decentralized blockchain architecture for securing data pipelines of heterogeneous information systems from attacks using a multi-hazard early warning system (MHEWS) as a case study.
- The proposed framework is implemented in the cloud using Azure Confidential Ledger – a ledger service that provides the ability to scale and operate blockchain networks on the Azure infrastructure.
- The effectiveness of our proposed framework is demonstrated and determined through the implementation and deployment of the Blockchain model in the cloud.

The rest of the paper is organized as follows, Section 2 discusses related works, and Section 3 outlines the application scenario with the presentation of the proposed model. Section 4 of this paper covers the methodology and approach for the experimental setup – for the implementation and deployment using the case study of MHEWS, and Section 5 provides the conclusion and future work.

2 Related Works

In the past few years, there has been a significant increase in the use of blockchain technology for security and privacy in information systems, the Internet of Things (IoT), healthcare, and cloud services. This growth is largely attributable to blockchain's capacity to secure data using cutting-edge encryption techniques, decentralization, Immutable Ledger, and Smart Contracts. Lin *et al*. [20] developed a model for Information Communication and Technology (ICT) e-agriculture systems with a blockchain infrastructure for use at the local and regional scale, with a focus on the specific technical and social requirements of blockchain technology for protecting ICT e-agriculture systems. Dey *et al*. [21] investigate the intentional use of blockchain technology for data validation, data storage, data security, and data transfer to create decentralized, effective, fault-tolerant, and interoperable e-agriculture infor-

mation systems. Liao *et al*. [22] suggests a paradigm that makes use of smart contracts to guarantee reliable communication between devices and sensors. The authors of [23] conducted a survey that provides comprehensive reporting on various blockchain studies and applications put forth by the research community, as well as their respective effects on blockchain and its use across other applications or scenarios; their findings showed that blockchain is increasingly being used in contemporary cloud- and edge-computing paradigms.

The application of blockchain for improving the Biomedical Security system (BDL-IBS) in healthcare sector was proposed by Liu *et al*. [31]. The authors introduced a blockchain and distributed ledger-based improved biomedical security system for improving the privacy and security of electronic health records for trust validation through linear decision-making. Yang *et al*. [32] proposed a blockchain-based approach to achieve privacy protection sharing for cloud federation, their approach allows the user to customize their data and sharing activities of the data based on the data privacy requirement.

Guo, Meiwen, *et al*. [6] investigate how blockchain technology can be used for environmental monitoring, with a focus on key metrics like the quantity of articles published, author collaboration networks, research institution networks, and keyword co-occurrence in this area over an eight-year period. Some of the nine elements utilized to assess the literature included the number of papers published, author collaboration networks, research institution networks, keyword co-occurrence, co-citation analysis, keyword clustering, keyword burst, time zone, and the distribution of countries and regions. The research employed Citeseer to visually examine various aspects of cross-over literature studies, including collaboration characteristics, contribution influence, and more. Moreover, the study utilized the data to identify the qualities and ultimately concluded the widespread acceptance of blockchain technology across various research fields (as shown in Figure 3).

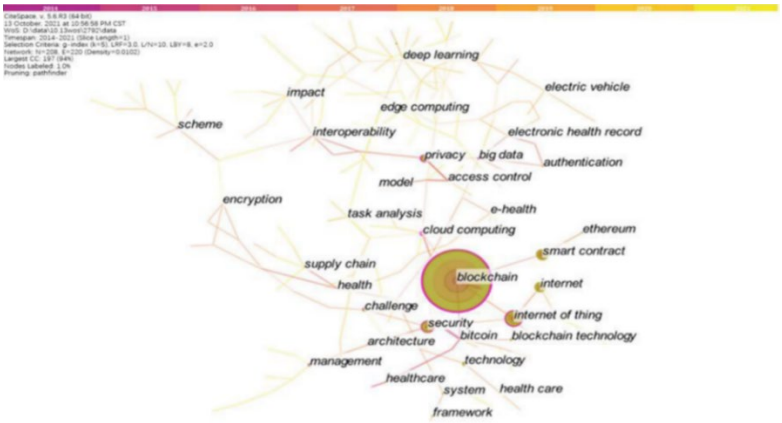

Fig. 12. Keyword concurrence [6].

3 Application Scenario and Proposed Model

In this section, the author presented the case study application scenario of an MHEWS in the environmental monitoring domain, along with the architecture of a heterogeneous information system that comprises a range of components such as legacy systems, wireless sensor networks (WSN), and more, all integrated to form a comprehensive monitoring system. This integrated system enables the collection, processing, and analysis of various data types for efficient and effective monitoring of environmental conditions.

3.1 Application Scenario

Information systems in the environmental monitoring context are heterogeneous by nature [17-18], [30], with interoperability a major challenge [24], [28]. Hence, components are isolated and integrated for processing based on the Extract, transform, and load (ETL) model [28]. There are three identified parts in the application scenario as shown depicted in Fig. 4 below, data producers, data pipeline and data consumers. Each part of the application scenario is integrated with other parts. The data producers in this case study of the integrated multi-hazard early warning systems (MHEWS) are the legacy systems, WSN and also standalone applications. The data pipeline consists of communication channels, which are either wired or wireless based on the infrastructure design [28]. The data consumers are the endpoint application utilizing the data from the sensors and enterprise systems. The details of these three parts are illustrated below:

Data Producers. In a typical MHWES, in-situ readings produced by different producers (sensors and devices) are incorporated into accompanying EWS in various structured formats and types are streamed via the communication channel to the repository for further processing [18]. In this case, examples of the parameters measured are temperature, pressure, moisture, and humidity.

Data Pipeline. This layer represents the entire communication channel of the MHEWS. The communication channel could be wired or wireless utilizing several communication protocols like WiFi, Bluetooth or ZigBee. Irrespective of the communication medium adopted, data are susceptible to several attacks in this layer [27]. The common encryption method offered by the communication protocols is not strong enough to prevent data compromise.

Data Consumers. Data consumers are software programs or tools that are utilized to process and analyze data for the extraction of valuable insights or information [18]. These applications are designed to cater to a variety of purposes, including business intelligence, machine learning (ML), predictive analytics, and data visualization [reference required]. The limitation of data consumers is that they heavily rely on the accuracy and completeness of the data provided to them [28]. If the data produced by

the data producers is not reliable, then the insights or information generated by the data consumers may not be accurate. Additionally, data consumers require a significant amount of computational power and storage space to process and analyze large amounts of data [18]. This can be a challenge for organizations that lack the necessary resources to support these applications.

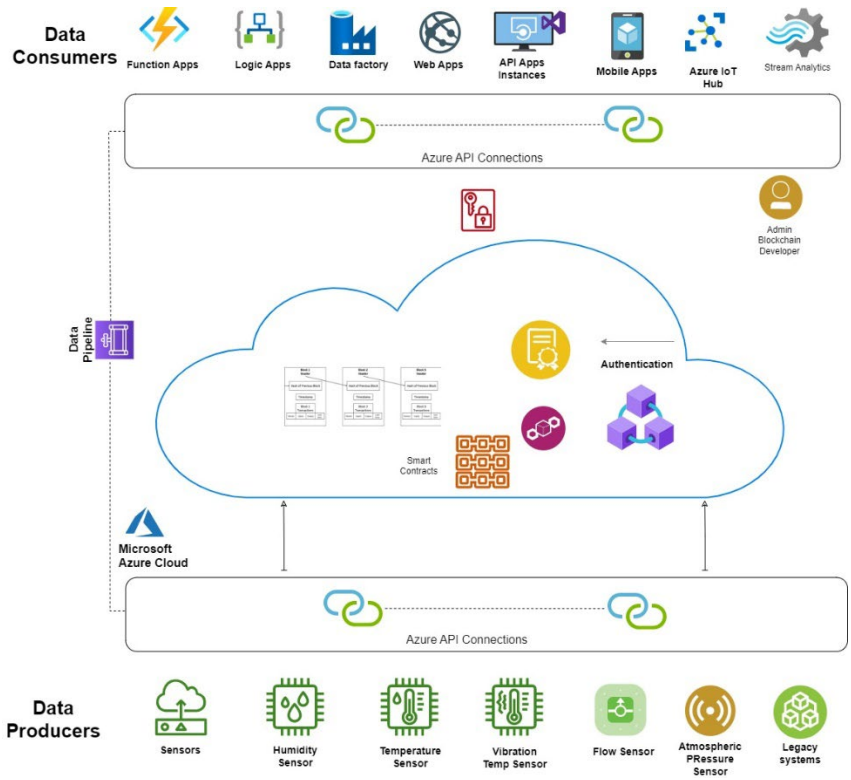

Fig. 13. An overview of an integrated Multi-hazard Early Warning System Architecture.

3.2 Proposed Blockchain-based Data Security Model

This paper proposes a Blockchain-based data security model (Fig 5) that applies blockchain technology in securing the data pipeline of an integrated multi-hazard early warning system, from the data producers to the data consumers. Each process and layer of our proposed model is described, outlining the data flow as data are generated, encrypted and validated in a hybrid model approach. The data obtained from the heterogenous data consumers in real-time are transmitted to the cloud using the appropriate Application Programming Interface (API) and are added to the blockchain infrastructure in accordance with the smart contract. The data is cloned and replicated across all the nodes in the distributed database network of the blockchain [25]. Therefore, a compromise of the data accessed in one node does not affect the accuracy of

the entire dataset in the cluster. The validation that the retrieved data is immutable is achieved by cross-referencing with the blocks stored on the ledger and all user transactions.

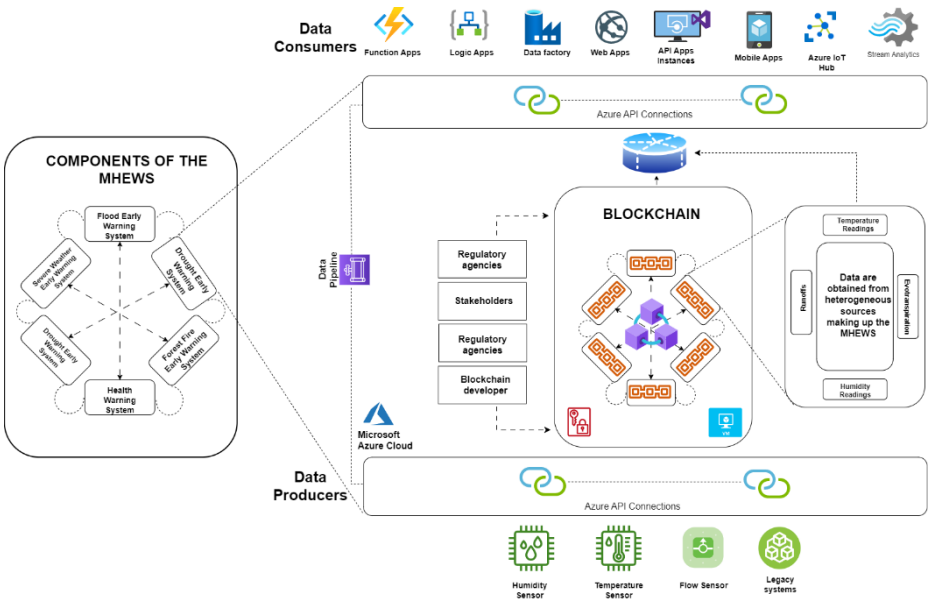

Fig. 14. A Blockchain-based Data Security Model for an integrated Multi-hazard Early Warning System (MHEWS)

4 Methodology

The implementation of blockchain technology for data security can be a complex process, herein the processes adopted are simplified and broken down into several steps:

- Define the use case: This first step involves the identification of the specific data or information that needs to be secured and how it will be used, followed by the specific business logic and conditions that need to be encoded into the smart contract. In the study - case of environmental monitoring systems, the minimum and maximum readings of the measured parameters are noted as conditions/rules encoded into the smart contract. For example, early warning indicators such as temperature can have low and high values of -50celsius to +50celcius respectively.
- Choose a blockchain platform: There are several blockchain platforms that support smart contract functionality, such as Ethereum or EOS with functionality that offers a complete end-to-end solution for developing, hosting,

and managing blockchain solutions. In a hybrid model design that allows data transmission to an online repository, the use of such services in Azure Cloud Security, which is best in class keeps both processes and data secure [19]. Azure Blockchain service supports Ethereum, Quorum Ledger, Corda, and Hyperledger Fabric. This research employs Microsoft Confidential Ledger (ACL), a managed and decentralized ledger for data entry that is supported by Blockchain. Data committed to the Confidential Ledger is made tamperproof in perpetuity by ACL through consensus-based replicas and cryptographically signed blocks, prohibiting intentional or unintentional data alteration.

- Write the smart contract code: Blockchains, such as Ethereum, allow for the creation and execution of smart contracts. These contracts are written in code and stored on the blockchain, making them transparent and secure. The business logic and conditions are coded using a programming language, such as Solidity.
- Test and deploy the smart contract: Test the smart contract using a virtual environment, such as a Remix Integrated Development Environment (IDE), to ensure that it functions as intended. Deploy the smart contract to the blockchain network, making it available for execution.
- Monitor and maintain: Monitor the network for any security breaches and perform regular maintenance to ensure the network remains secure.

In this case study, the ACL is created in the cloud, based on the proposed hybrid architecture. In the cloud platform, the model is implemented, starting with the creation of the resource group that will contain the resources and services required for the implementation and deployment of the infrastructure. The ability to implement, deploy and scale is considered one of the main advantages of cloud services. Using a component of the MHEWS, drought early warning systems (DEWS) services are replicated in the cloud platform, starting with the configuration of the in-situ sensors and legacy systems to transmit environmental readings to the cloud repository using ledger APIs support certificate-based authentication process with owner roles as well as Azure Active Directory (AAD) based authentication and also role-based access. The data pipelines from the endpoints to the ledger are transmitted over a TLS 1.3 connection, which terminates within the hardware-backed security enclaves (Intel® SGX enclaves).

The secure ledger is accessible via REST APIs, which can be integrated into new or existing applications using JSON resource connection strings as captured in a code snippet (Fig. 6) and Azure service in Fig. 7 below. The data streams are created as blocks in blob storage containers belonging to an Azure Storage account in an encrypted format and committed to the ledger. Basic operations such as create, update, get, and delete are supported by the Administrative APIs.

Fig. 15. Code Snippet – A JSON REST API for accessing the MHEWS ACL in the Azure.

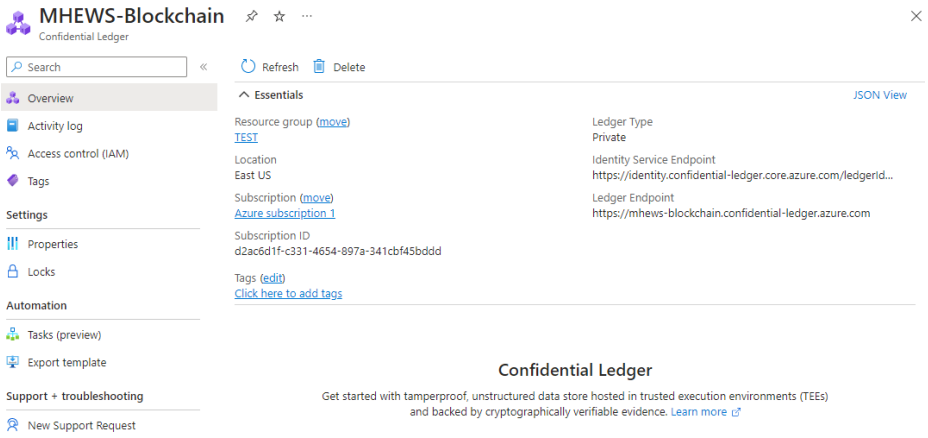

Fig. 16. The MHEWS Blockchain service in Azure Cloud.

Smart contract manages the nodes to govern the consensus in the ledger. Smart contracts are implemented on the blockchain to automate the process of data validation, reducing the potential for human error or manipulation. Typically, the code of a smart contract is composed in a high-level programming language such as Solidity before being compiled into bytecode and uploaded to the blockchain. The smart contract that can be deployed on our blockchain will be written in Solidity and Remix. However, for test purposes before deployment, Truffle provides a testing framework and asset pipeline that makes it easy and quick to deploy contracts, develop applications, and run tests on a local server using tools like Ganache. Using the Temperature parameter from the deployed sensors of the DEWS, a smart contract is created for experimental purposes and deployed on the local server using Remix as captured in Figure 8 below.

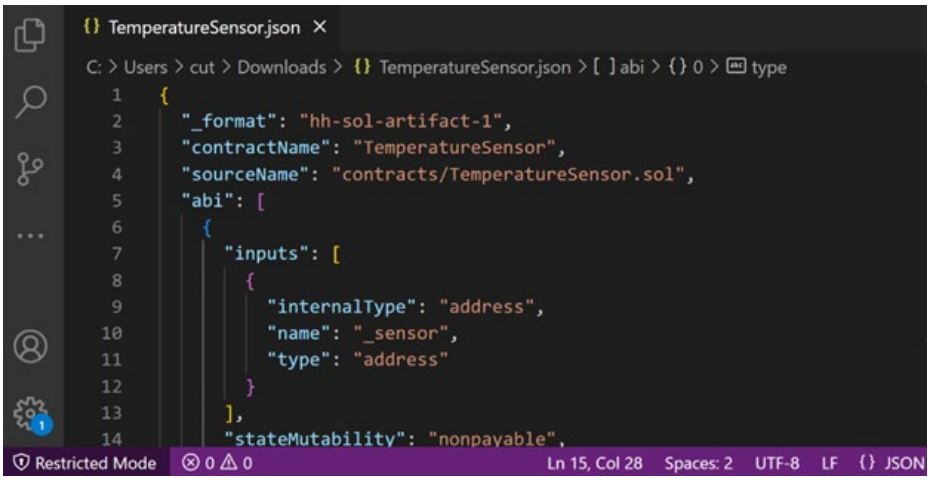

Fig. 8. Using the *Temperaturesensor.sol* smart contract as an example in Remix for testing purposes.

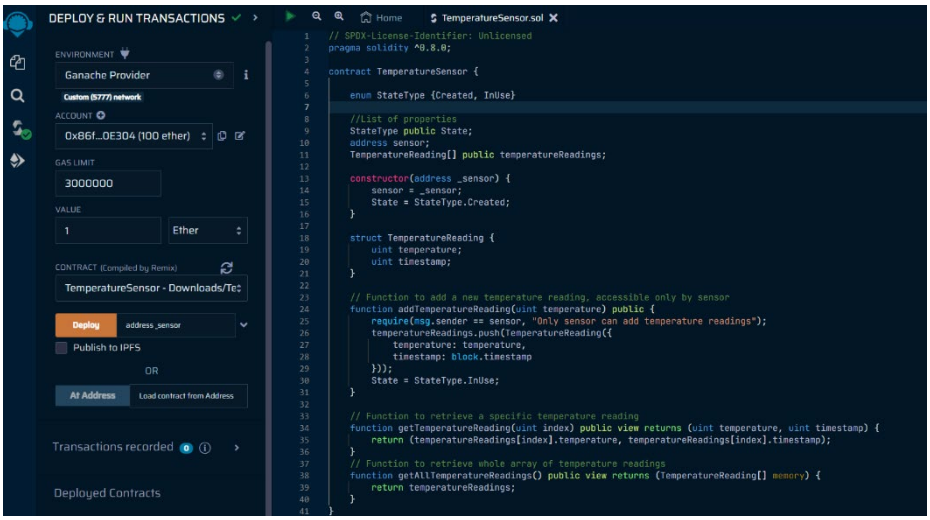

Fig. 9. The smart contract is deployed and tested on a local server before deployment to the cloud in Remix testing environment.

Publishing and using the smart contract created for the parameters of the reading involves copying the ledger endpoints to the Remix and selecting a Web3 Provider using the generated Azure ledger URL. Once connected, the contract is deployed, and interaction with the contract is achieved through Remix for testing purposes.

5 Conclusion

Blockchain is a decentralized, distributed ledger that eliminates the need for a trusted third party or single point of failure. The presented blockchain security model in the experimental setup demonstrated has guaranteed the security of data pipelines in heterogeneous information systems such as the MHEWS case study. This model has the ability to work with new or existing applications similar to any PaaS, and IaaS models, using cloud-based apps and storage. The ACL in our Blockchain system creates an ever-growing list of ordered information called blocks to create a digital ledger. This list is made possible by a decentralised, peer-to-peer network. Each transaction is then automatically verified by the network itself after being included in a block with a cryptographically signed signature. This enables the security of environmental monitoring data by creating a decentralized and tamper-proof system for storing and sharing data.

The use of blockchain can ensure that the data is accurate, and reliable and cannot be altered without leaving a traceable record. Overall, the presented architecture offers distinct benefits for data integrity, such as immutability, tamper-proofing, and append-only operations in the relevant domain. These capabilities, which guarantee the preservation of all records, are perfect when it's necessary to preserve essential metadata records, such as for archive and regulatory compliance needs. While the presented solution worked in the context of MHWES, the applicability in other types of heterogeneous information systems with different security challenges has not been substantiated. Therefore, further research is needed to investigate the feasibility and effectiveness of using blockchain for securing data pipelines in other domains. Future work will explore the implementation practicability in other large enterprise information systems and focus on the performance metrics of implementing the model in a hybrid domain and the effect of containerization of application components as a microservice.

One potential limitation of using blockchain technology is its computational and energy-intensive nature, which can result in high transaction costs and slow processing times. Additionally, the security and immutability of the blockchain can also create challenges if errors or discrepancies are identified in the data that need to be corrected, as the original data cannot be edited or deleted. Finally, the adoption of blockchain technology may require significant changes to existing systems and processes, which can be costly and time-consuming.

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The role COBIT could play in transitioning IT Governance (ITG) to Enterprise Governance of IT (EGIT) in South African HEIs.

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Abstract.

This article outlines the South African KING IV Code of Conduct and the South African Department of Public Services and Administration (DPSA) Information Technology Governance (ITG) guidelines, charting their evolution over time. The central argument advanced in this article is that a comprehensive approach to IT governance is essential, underscoring the interdependent relationship between ISACA's Control Objectives of Business Information Technology (COBIT) and the standards and criteria specified in the DPSA requirements and the King IV Code of Conduct. The article emphasises the critical role played by the COBIT Framework in facilitating the transition from ITG to Enterprise Governance of IT (EGIT). The study concludes that the COBIT Framework may be the most suitable framework for higher education institutions (HEIs) to adopt to create a roadmap for implementing EGIT that is strategic, comprehensive, and organization-wide in scope. The alignment of COBIT 2019 with existing standards and frameworks supports this conclusion.

Keywords: Information Technology Governance (ITG), Enterprise Governance of Information Technology (EGIT), COBIT 2019, IT Governance and Management Framework (IGMF), Higher Education Institutions, Developing Countries.

1 Introduction

Corporate governance within the South African context is best defined by the Institute of Directors South Africa (IoDSA) as "the exercise of ethical and effective leadership by the governing body towards the achievement of ethical culture, good performance, effective control and legitimacy" [1]. As such, corporate governance aims to mitigate widespread risks from mismanagement to disorderly conduct, which could cripple the organisation's strategy's implementation and draw its reputation into disrepute.

The Institute of Internal Auditors South Africa published a Corporate Governance Index (CGI) for 2020 by targeting one hundred and ninety Chief Executives Officers. By evaluating dimensions such as ethical value and culture, compliance, leadership,

operational risk, external risk, performance management, internal audit and alignment to the King IV codes of conduct, the index established a 2.8 rating out of 4 for South Africa compared to a 3.2 rating out of 4 based on the 2013 CGI report [2].

This investigation highlighted that, due to the Covid 2019 pandemic, issues such as benefits realisation, risk and resource optimisation became futile, especially when sound governance practices, especially alignment between Corporate and IT governance, needed to be managed proactively.

Authors such as Rathod [3] warn that governance should be managed proactively through streamlined governance and managerial processes, ensuring cost-effectiveness. Rathod [3] explains that processes only become streamlined when the regime to be followed is "applied" (thus managed) and "explained" (thus controlled) in a repeatable manner. Rathod [3] conclude that such actions must be driven by the board, where governing bodies promote a culture of compliance and assurance to vitalise positive behaviour amongst stakeholders and boost organisational reputation [3].

Nowadays, governing bodies must adopt corporate governance, risk, and compliance imperatives that negate a conscious decision and focus on Information and Communications Technology (ICT). According to Gregory et al.[4], this requirement stems from organisations' dependency on ICT to support and enable business processes, strategies, and objectives [4]. Information Technology Governance (ITG) thus relates to how ICT decisions are made to support enterprise goals, objectives and strategy and are essentially driven by IT department personnel through a CIO [5, 6]. However, Gregory et al. (2018) warn that this approach leads to situations where ICT starts acting as a business within the business. In such instances, the ICT department often claims autonomy by providing products and services to other functions outside the organisation's governing bodies' purview and control. Such an arrangement creates substantial problems/conflicts related to misalignments between spending, the decision-making authority of governing bodies, and those who delegate IT responsibilities and strategy [4]. Such a deliberate separation of power and decision rights undermines organisational value creation from IT-related investments and contradicts the spirit of business and IT alignment [4]. ICT Governance should be subordinate to Corporate strategies, goals, governance, risk and compliance. Of interest is that authors such as McCue [7] earlier warned against ICT being divorced from Corporate, arguing that such actions ultimately result in:

- Lack of oversight in roles and responsibilities, risk management and business/ICT alignment [8].
- IT-related investments are getting caught in scope creep, exceeding time and budget constraints, and ICT-related projects fail to support organisational objectives [9].
- Mismatches between the short-term goals of ICT departments versus the long-term goals and objectives of governing bodies and executive management.
- Failure of infrastructure for delivering ICT services to external and internal stakeholders [10]
- Lack of adherence results in non-compliance from a regulatory perspective [11]
- Duplications in ICT processes and ICT security breaches [12].

However, when IT Governance becomes an integral part of corporate governance, the board and not the CIO, oversees the definition and implementation of the IT processes, structures and relational mechanisms for the benefit of the whole organisation. This enables IT people to execute their responsibilities to support business/IT alignment and create business value from IT-enabled business investments, something institutions such as the Information Systems Audit and Control Association (ISACA) have been proposing for several years. The transition from CIO governance control to Board control signals a distinct shift in managers' minds, a move away from IT Governance to Enterprise Governance of Information Technology (EGIT) [13].

This article begins by examining the significance of EGIT and its impact on Higher Education Institutions (HEIs). It then delves into the South African perspective, shedding light on the journey from ITG (Information Technology Governance). Subsequently, it focuses on ITG practices, providing an in-depth analysis of their implementation and effectiveness. Finally, the article concludes by discussing the implications of these practices and their potential for improving IT governance in HEIs. By exploring the role of EGIT, understanding the South African context, and evaluating ITG practices, this article aims to contribute to a comprehensive understanding of effective IT governance strategies in the realm of higher education.

1.1 Research Question and Hypothesis

This studies research question is what is the interdependent relationship between ISACA's Control Objectives of Business Information Technology (COBIT) framework, the South African Department of Public Services and Administration (DPSA) Information Technology Governance (ITG) guidelines, and the South African KING IV Code of Conduct, and how can a comprehensive approach to IT governance be achieved in HEIs?

The derived hypothesis is that implementing a comprehensive approach to IT governance, integrating ISACA's COBIT framework, the South African DPSA ITG guidelines, and the KING IV Code of Conduct will improve IT governance practices and outcomes in South African HEIs. By examining the interplay between these frameworks and guidelines and identifying potential challenges and best practices, this study seeks to provide practical insights and recommendations for HEIs to enhance their IT governance strategies and ensure the efficient and secure management of their technological resources.

1.2 Limitations and research contribution

The primary focus of this study is on the South African context, which imposes certain limitations on its generalizability to other regions or countries. It is crucial to acknowledge that the findings and conclusions of this study may not directly apply to diverse cultural, legal, or organisational contexts. Specifically, the study concentrates on the implementation of IT governance frameworks in higher education institutions (HEIs), and therefore, its findings may not be readily applicable to other sectors or industries outside the education domain. The study identifies potential challenges and best practices in implementing a comprehensive approach to IT governance in HEIs.

By uncovering these insights, the study offers practical recommendations for HEIs to enhance their IT governance strategies and improve the management and governance of their technological resources. Overall, the research contributes to the advancement of knowledge and understanding in the field of IT governance and EGIT in HEIs, providing valuable insights and recommendations for practitioners, policymakers, and researchers working in the area of IT governance, technology management and Enterprise Governance of Information Technology in educational institutions.

2 Towards Enterprise Governance of Information Technology (EGIT) in HEI's

EGIT, as an updated definition, centers on governing bodies as central pillars with oversight on the exact relational mechanisms, processes and structures of IT Governance (ITG) and, as such, extends to business/IT alignment and the creation of value from IT-enabled investments [14]. This viewpoint propels that IT Governance should be perceived as something other than a separate function that focuses on the confines of the Information Technology (IT) department and its IT-related responsibilities alone. De Haes and Van Grembergen [14] and Awais and Gill [15] explain that this not only disadvantages efforts to evaluate, direct and monitor the diffusion of IT Governance but, more importantly, lead to neglect and the avoidance of making ICT-related decisions in support of the business strategy. To counter such practices, the KING IV report on Corporate Governance in South Africa (2016) elaborates on governing bodies' responsibilities and proposes using best practices frameworks and standards to define organisational goals, policies, and plans, especially concerning IT Governance [1].

Many frameworks have been developed and promoted as "best practices" to aid the design, implementation and understanding of IT Governance and now EGIT. Some of the most popular and valuable frameworks include the Control Objectives for Information and Related Technology (COBIT IV, COBIT 5, COBIT 2019)[5], the International Standard for Corporate Governance of ICT (ISO 38500)[6] and the Information Technology Infrastructure Library (ITIL version 3 and 4)[7] amongst some [16, 17].

From the South African perspective, efforts to incorporate such frameworks into IT Governance started with the King 3 report on corporate governance for South Africa in 2009, where ICT was no longer perceived as a separate enabling function within the organisation but as a central pillar to the business strategy. The King 3 Report outlined five focus areas which pertain to 1) resource management to ensure that IT infrastructure is optimised in support of the business strategy, 2) risk management

[5] COBIT is a framework for the governance and management of enterprise IT https://www.isaca.org/resources/cobit

[6] ISO 38500 is a standard for the governance of IT in organisations https://www.iso.org/standard/62816.html

[7] ITIL is a framework for IT service management https://www.axelos.com/certifications/itil-service-management

optimisation to guarantee IT Business Continuity Planning (BCP) and Disaster Recovery Planning (DRP), 3) value delivering to ensure that the organisation obtains and realises the value in IT-enabled investments, 4) strategic alignment to ensure that the business strategy is aligned to the IT strategy and that there is synergy between the board and management and lastly 5) performance measurement to monitor the effectiveness and efficiency of enterprise-wide IT [18]. These five focus areas aligned with the COBIT IV and later COBIT 5 focus areas: benefits realisation, risk and resource optimisation and performance management [13].

In November 2016, the King IV report on Corporate Governance for South Africa replaced the King 3 report. Updated features comprised a change in the voluntary (apply or explain) basis for governance compliance to a compulsory (apply and explain) basis. King IV now applies to private companies with governing bodies and organisations listed on the Johannesburg Stock Exchange (JSE). The essence of King IV is to extract value in leadership continuity and enhance resilience, reputation and credibility in the organisation coupled with heightened resistance to fraud [19]. Although King IV (as stated in principle 12) aligned strongly with the COBIT 5 framework, King IV emphasises that governance should be addressed separately as technology governance and information/data governance and sets the board as the responsible agent to oversee and delegate emphasising a stronger focus on EGIT than ITG. Lastly, King IV recommends a series of EGIT Governance practices where enterprise boards emphasise greater disclosure on compliance with applicable laws regarding the reality space the organisation operates within.

From a public sector perspective, the South African government realised the need to prioritise IT governance in government after the Auditor General of the Republic of South Africa (RSA) issued recommendations over a review period from 2008 to 2010. Recommendations stemmed from 1) undefined ICT governance roles and responsibilities within state organs, 2) inadequate performance measures to support service delivery, 3) unstructured guidelines, policies and standards which are inconsistent in implementing ICT governance structures and do not address process-related risks and lastly,, 4) the need for an ICT governance framework for state-wide implementation to address ICT risks based on best practices and defined processes. Such recommendations propelled the need to establish the public service Corporate Governance of Information and Communication Technology Policy Framework (CGICTPF), a collaborative framework developed by the Department of Public Service and Administration in conjunction with the Auditor General RSA and the Government Information Technology Officer Council (GITOC). The main reason for the framework was to remedy the failures of Government Information Technology Officers (GITOs) to fulfil their strategic mandates and uphold IT governance controls across all spheres of government. The framework was to ensure that ICT is governed and managed effectively and efficiently by executive management, accountable to political and strategic leadership. This was all in a bid to enable organs of the state and government departments to be guided by principles and practices and coupled with best practices from the King 3 code of conduct, COBIT IV (revised later to include COBIT 5) and the ISO 38500 standards on ICT corporate governance [20].

The CGICTP Framework outlines seven core principles for the corporate governance of EGIT from a public sector perspective. Principle one denoted that the mandates stem from political executive authority as a governing body providing oversight to achieve IT goals and objectives. Principles two and three reflect on the strategic mandate under the responsibility of the Head of Department (HoD) as an accounting officer of the executive management to ensure that strategic plans are put in place to realise IT goals and objectives. Principle four outlines the importance of business and IT alignment to ensure that IT-enabled investments are acceptable, suitable and up-to-standard from an executive management perspective under the HoD's purview. In addition, it sought to ensure IT service management prioritisation in support of business goals and objectives. Principle five ensures that IT expenditure is controlled, monitored and managed appropriately to extract value and benefits and that investments support business goals and objectives. Principle six gives executive management the responsibility of ensuring that IT risk management practices are adhered to and that audits are conducted to ensure compliance. Lastly, principle seven addresses organisational culture and behaviour where leadership (political and strategic) buy-in is critical for overall success in IT service delivery [20].

In support of the CGICTP Framework, the South African Department of Public Service and Administration (DPSA) developed an implementation guide to guide public sector entities with adoption and implementation. As a result, twelve minimum governance and management processes were recommended to guide public entities based on originally COBIT IV and later COBIT 5 principles. The prioritisation of processes stemmed from IT audits conducted by the Auditor-General of South Africa (AGSA) and outlined two non-critical but essential COBIT processes: the assurance of Governance Framework Setting and Maintenance and the management of IT Continuity. In addition, guidelines recommended that the following critical COBIT processes, namely, the management of an IT Managerial Framework, IT Strategy, IT Enterprise Architecture, IT Portfolio), IT Suppliers, IT Risk, IT Security, IT Programmes and Projects, Operations and the monitoring, evaluation and assessment of IT Performance and Conformance [21].

The COBIT 2019 framework, promulgated at the end of 2018, is an evolved version of COBIT 5. Compared to the previous COBIT 2019 focus on new trends and technologies and introduce greater flexibility, more contemporary concepts, updated alignments to meet global standards, and enhanced use of best practice frameworks. Within COBIT 2019, various changes are guided by six governance system principles. The first principle involves providing stakeholder value. In this, COBIT 2019 aims to satisfy and meet stakeholders' needs by creating value for organisations while helping them realise benefits and optimising risk levels [22]. The Second principle involves enabling a holistic approach, where COBIT now looks at the bigger picture, not just individual components. The third principle involves building a dynamic governance system. This ensures that a change's impact must be considered throughout the total organisational governance system. The fourth principle involves separating governance from management, as they have different activities, objectives and processes, serve different purposes, and have different organisational structures [23]. The fifth principle involves tailoring enterprise needs. On this basis, COBIT 2019 pro-

motes design factors enabling enterprises to customise and prioritise governance system components. COBIT 2019 is designed to be customisable, enabling organisations to address unique needs and objectives [24]. Finally, the sixth principle reinforces the EGIT principle of end-to-end governance, where COBIT focuses on managing information and related technology on an enterprise-wide scale. [13].

COBIT 2019 puts forth seven components of a governance system, formerly known in COBIT 5, as enablers. These components collectively define and address the enterprise-wide functions that make the build-up of organisations in a bid to derive organisational value from IT-enabled investments. These include 1) processes, 2) organisational structures, 3) principles, policies and frameworks, 4) information, 5) culture, ethics and behaviour, 6) people, skills and competencies, and 7) services, infrastructure and applications [25]. COBIT 2019 thus introduces design factors to turn COBIT 2019 into a holistic framework for Enterprise Governance of Information and Technology (EGIT), as it provides a comprehensive set of guidelines and practices spanned across focus areas (information security, risk management, DevOps etc.) for the effective management and control of IT-enabled investments in organisations. As mentioned, through these design factors, organisations can customise their enterprise governance system depending on their needs appetite, regardless of their enterprise type. This customisation opens up the organisation to a 1) contextual analysis of factors beyond its control, such as compliance requirements, 2) strategic analysis of factors within its control, such as enterprise goals and strategy and lastly, 3) tactical analysis of factors influenced by implementation methods such as technology adoption strategies [26]. Regarding assessment, COBIT 2019 shifts from measuring capability to maturity levels and increases its governance and management processes from thirty-seven to forty in support of a more universal and holistic EGIT programme [27]. Issues such as data, projects and assurance are now explicitly addressed.

By applying a Goals Cascade, Cobit 2019 introduces specific focus areas to address issues such as Information Technology risk, DevOps, privacy, cloud computing, digital transformation, and information security [28]. In essence, the COBIT 2019 framework becomes an umbrella framework aligned to various international standards and frameworks, including the ISO series (20000[8], 27000[9], 38500[10]), NIST Cybersecurity Framework[11], CMMI[12], ITIL and TOGAF. As discussed briefly in the next section, as input to the COBIT 2019 Framework, references are made to other standards and frameworks such as TOGAF and ITIL. COBIT 2019 also include guidelines provided within the RSA KING IV Code of Conduct, as it relates to and references principle twelve technology and information governance. [1, 29].

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[8] ISO 20000 is a standard for IT service management https://www.iso.org/standard/70636.html

[9] ISO 27000 series of standards relates to a set of standards on information security https://www.itgovernance.co.uk/iso27000-family

[10] ISO 38500 series of standards relates the governance of IT in organisations https://www.vanharen.net/blog/isoiec-38500-for-it-governance-in-3-minutes/

[11] NIST framework helps organisations combat cybersecurity risks https://www.nist.gov/cyberframework

[12] CMMI is a process level improvement model to gauge maturity levels and performance https://cmmiinstitute.com/cmmi

The IT Infrastructure Library (ITIL) v4 as a best practice framework for IT service management shares many overlapping themes with COBIT 2019, from ITIL guiding principles to the thirty-four management practices spanned across general, service and technical management practices. As such, 1) COBIT's EDM domain is mapped to ITIL's general management practices, 2) COBIT's APO is mapped to ITIL's general and service management practices, 3) COBIT's BAI is mapped to ITIL's general service and technical management practices, 4) COBIT's MEA is mapped to ITIL's general management practice and 5) COBIT's DSS is mapped to ITIL's service and technical management practices. A continual improvement process overarches ITIL v4 to improve services and create value. This is mapped to COBIT's Monitor, Evaluate and Assess (MEA) domain, which addresses assurance, compliance, internal controls, performance and conformance monitoring [30]. Alignment also exists between COBIT 2019 and the Open Group Architecture Framework (TOGAF v8), where overlapping's relate to the Architecture Board and EDM04 on ensured resource optimisation from the board level. In addition, TOGAF phases/activities are referenced and aligned to COBIT's management objectives and practices in the Align, Plan and Organise (APO) domain with particular reference to APO03 Managed Enterprise Architecture [31].

3 Information Technology Governance from a South African Higher Education Perspective

The South African Higher Education Act of 1997 [32] gave rise to annual reporting by Higher Education Institutions (HEIs) based on the specifications enshrined in the 2003 regulations for annual reporting by HEIs based on the KING 2 codes on corporate governance [33]. The amended regulations of 2014 were updated to include the KING 3 codes of conduct and were geared to guide HEIs through an annual reporting framework from a governance and management perspective to ensure that reporting is done in a structured and consistent manner. Updated regulations guided HEI's financial reporting, ensuring that targets were met in line with strategic and operational objectives. As part of the 2014 amended regulations, an updated implementation manual outlined the governance responsibilities associated with HEI Councils, which from an ICT perspective, relate to 1) being responsible for ICT governance through effective and ethical leadership coupled with an appropriate committee, 2) understanding the inseparability between organisational strategy, performance, sustainability, risk and ICT, 3) ensure that ICT operations function accordingly and lastly, 4) ICT regulatory compliance and the utilisation of ICT best practices and standards to support Teaching and Learning (T&L), Research and Innovation (R&I) and Community Engagement (CE). This illustrates a deliberate shift towards EGIT expanding the scope of IT Governance to a broader, integrated, and strategic view of IT within the organisation where the Vice-Chancellor's responsibility from an ICT perspective is extended to institute broad operational measures encompassing ICT governance and management, risk management and integrated reporting together with executive management [34]. In many instances, HEI governing bodies in South Africa now needed

to play a more leading role in demonstrating that they regard ICT governance as a top priority within the greater corporate governance scheme by taking the necessary decisions whilst providing oversight.

4 Information Technology Governance in practice

According to Aasi et al.[35], by the mid-2010s, only a few organisations structured and organised ICT governance to ensure that it meets the needs of all stakeholders or those that could be affected by the institution's decisions. They argue that this stems from 1) failures to address organisational culture, ethics and behaviour and leadership support for ICT, 2) the lack of a coordinated, collaborative and comprehensive approach to information security, information accessibility, information risk and information privacy, and the strategic implications when such coordination is not in place and lastly, 3) the lack of strategic ICT expertise and decisions that are aligned to the institution's goals and objectives and no accountability for bad ICT decision-making [36].

From a South African perspective, Viljoen [37] outlines that 43% of South African HEI's IT directors during a 2003 survey highlighted the need to implement IT governance frameworks and practices as IT services and infrastructure fused with core academic and administrative activities. This advance was driven primarily by security issues, budget constraints, IT value, HEI complexity and the rise of e-learning across HEIs. On determining IT governance process maturity levels, Johl and Flowerday [38], using COBIT 4.1 as a best practice framework from a survey of 23 South African HEI's revealed a 1.8 process maturity level average out of five (optimised). Regarding the maturity model, South African HEIs fell into level 2 (Repeatable but Intuitive), where the IT functions are tactically efficient but inconsistent in meeting the needs of customers and vendors. Mathinya [39] investigated obstacles to good IT governance by looking into the University of the Witwatersrand (South Africa) and found that 1) the lack of IT skills within the HEI IT machinery, 2) the capacity to measure the value of IT services, 3) bureaucracy, delayed policy approvals and resistance to change and lastly 4) disorganised governance committee structures contributed immensely towards a sound IT governance environment at the university.

Authors such as Bates [40] thus stress that for governing bodies to discharge their ICT fiduciary duties, it is essential to distribute responsibilities across various subcommittee groups for shared responsibilities. In clarifying his argument, Bates [41]proposes that subcommittees should span from the following functionaries related to EGIT, namely:

- Portfolio management to ensure that all projects/services comply with and meet the overall strategic objectives of the organisation,
- Resource management to ensure those cost implications are taken into consideration in support of organisational objectives,
- Policies and standards to ensure that the organisation adheres to regulatory requirements and protects the quality and integrity of data and

- Risk management and compliance to ensure that a risk register is maintained and to ensure that compliance is adhered to.

Historically, HEI's goals and strategies, including the ICT strategy, were in support of the universities core business processes of Teaching and Learning (T&L), Research and Innovation (R&I) and Community Engagement (CE) [42].

From a technological standpoint, HEIs accumulate vast amounts of decentralised applications and services distributed across all facets of the institution over time. Gregory, Kaganer [4] outline that this was due to the autonomous running of ICT departments supported by IT Governance outside the purview of EGIT and the organisational strategy with unstreamed deliveries of ICT products and services to business functions. The problems that arose were the result of the following:

- Duplications and overlaps in the functionalities of systems and resources
- Old operational systems that are still integral within the institution without support that requires bridging
- Lack of integration as applications and services do not communicate with each other
- Lack of coordination between the roles and responsibilities associated with ICT resources and reporting
- Improving the ICT portfolio of institutions by identifying new technologies to aid HEI institutions' three primary core objectives: Teaching and Learning (T&L), Research and Innovation (R&I) and Community Engagement (CE).

Such shortfalls and lack of oversight make it untenable to manage and track the diffusion of ICT-related investments effectively and efficiently within HEIs. According to Bates [43], solving such shortfalls for HEIs would require that such institutions understand stakeholder drivers and needs and require that they view their applications and services holistically. Bates [43] proposes that this would entail adopting a governance framework to align and centralise all ICT resources for better collaboration and efficient management [40], i.e., a transition from Information Technology Governance (ITG) in isolation to the more "holistic" Enterprise Governance of Information Technology (EGIT).

Just before the Covid 2019 pandemic, Bii and Rukwaro [44] investigated the factors that led to information systems failures among HEIs in Kenya. Findings revealed that ICT systems failed due to the following:

- Low levels of stakeholder confidence and buy-in. When stakeholder engagement is low, this is due to many factors such as inadequacies in system requirements resulting in mismatches in stakeholder needs, resistance to change in adopting new systems, communication breakdowns resulting in a loss of confidence and support a lack of training [45]. From a COBIT perspective, this translates into a lack of oversight in 1) organisational culture, ethics and behaviour and 2) processes such as ensured stakeholder engagement [29]
- Management interference is another factor in ICT system failures. This is due to blurred roles and responsibilities between management and technical teams, caus-

ing conflicts, miscommunication, and confusion within project teams, compromising systems' effectiveness, integrity and efficiency [46]. This over to management not being forthcoming with skills training and availing financial support and, from a COBIT perspective, translates into a lack of 1) organisational structures, 2) people, skills and competencies, 3) managed relationships, 4) managed requirements definition and lastly 5) managed organisational change [29].

- Poor change management practices where changes are not controlled result in scope creep, missed deadlines, misaligned objectives between project teams and management/governing bodies, downgrades in quality and unreliable systems. In addition, a lack of requisite skills and experience translates into delays and poorly designed systems [47]. From a COBIT perspective translates into a lack of 1) processes, 2) principles, policies and procedures, 3) information flows, 4) managed human resources, 5) managed IT changes, 6) managed IT change acceptance and transitioning and lastly, 7) managed projects [29].
- Inappropriate use of infrastructure, services and applications can lead to ICT system failures and equate to a myriad of information security risks which have the propensity to compromise systems. Additional components include technical problems/factors such as overloading, hardware, software, network, and human errors. Maintenance factors such as untrained staff, inadequate testing and configuration, and the failure to keep ICT systems up-to-date contribute to this conundrum [48]. From a COBIT perspective translates into a lack of 1) processes, 2) services, infrastructure and applications, 3) managed enterprise architecture, 4) managed security, 5) managed data, 6) managed availability and capacity, 7) managed operations and lastly 8) managed continuity [29].

From a Higher Education perspective, IT Governance failures during the Covid 2019 pandemic revolved around the following:

- Insufficient IT infrastructure related to surges in demand for online services [49],
- Lack of contingency planning and inadequate security measures resulting in cyberattacks where the University of Utah had to pay $457k after falling victim to a ransomware attack [50]
- Insufficient training and support in the use of digital tools and platforms during the pandemic, which heightened frustrations and hampered productivity [51]

In promoting the use of the COBIT 2019 Framework, ISACA [13] argues that it should be goals, risks and strategies that drive response to the implementation of Information Technology related issues, where issues are driven by risk assessments that span from IT-related incidents, regulatory requirements, duplications in processes and IT-enabled changes, among many other challenges. As early as 2005, authors such as Symons [52] and later Alkhaldi et al. [53] started to warn that ICT governance should also comprise the dimensions of risk and security management, where risks and security, as Bustamante et al. [54] contest, are the protection of the organisation from cyber-crime. During the Covid 2019 pandemic, universities have become more dependent on ICT functions, forcing them to transform their institutions from contact to distance learning through e-learning models [55]. This transformational process oc-

curred parallel to a rise of cyber-crimes [56], necessitating universities to understand stakeholders' needs and how much needs link to goals, risks and strategies, especially concerning mitigating risks and security issues. The Covid 2019 pandemic also presented unique challenges to HEIs concerning business continuity and privacy. Privacy controls became problematic as many organisations needed to adapt IT infrastructure and enterprise architecture to support remote work and adapt enterprise-wide processes in response to the pandemic from a managerial and governance perspective [57].

From a practical perspective, HEIs responding to these constraints benefited from best practice frameworks and standards, such as COBIT 2019, to mitigate the effects of the Covid 2019 pandemic. This entails identifying and prioritising critical governance and management objectives as Harits, Gernowo [58] contests include ensured risk optimisation (EDM03), managed risk (APO12), managed security (APO13), managed service requests and incidents (DSS02), managed problems (DSS03), managed continuity (DSS04), managed security services (DSS05) and lastly managed compliance with external requirements (MEA03). Establishing appropriate organisational structures to support risk management and decision-making, as Juiz and Gómez [59] argue, is detrimental to good EGIT practices in HEIs. As a Cobit 2019 component, it is essential to establish IT principles, policies and procedures that support the core objectives of an HEI, such as the North-West University (South Africa) efforts to develop policies during the peak of the pandemic such as data privacy, remote working and digitisation policies etc. NWU-Registrar [60]. Lastly, the Cobit 2019 framework provides HEIs with mechanisms for IT performance management to evaluate and monitor the performance of IT services, infrastructure, and applications across metrics to solidify business/IT alignment. With the aid of the COBIT 2019 framework and Capability Maturity Model Integration (CMMI) - based process capability scheme, Utomo, Wijaya [61], investigating IT governance implementation in an HEI, found that its current capability/maturity level was at level 1 out of five, translating into processes that are not well organised (documentation of only 20%) that are at the initial/ad-hoc stages. In addition, the target capability/maturity level of the HEI was projected at level 2, translating into processes that are repeatable but still intuitive (documentation at 40%).

5 Conclusion

Within the South African context, efforts to adhere to good governance best practices are defined within the King IV Code of Conduct and the DPSA CGICT policy framework requirements and seek to build a bridge between shareholders, stakeholders, and management to ensure that accountability and oversight are exercised continually according to best practices and standards defined in the macro-environment. A full-rounded evaluation of the corporate governance effectiveness of state entities revealed that seven dimensions outline effectiveness. It includes an assessment of ethics, compliance, leadership, operational and external risks, performance management through human capital and ICT, and internal auditing as critical success factors. According to the Corporate Governance Index (CGI) report for 2020, most South

African organisations performed poorly, indicating that work still needs to be done to drive organisations towards adopting good governance practices, especially IT governance practices. It was found that when IT governance is divorced from corporate governance, reputations suffer immensely, resulting in organisations losing competitive advantages, financial losses and fines resulting from non-compliance and general instability due to conflicts between internal stakeholders, business and IT, governing bodies and executive management. These conflicts became prevalent during the Covid 2019 pandemic through a disorganised pursuit of EGIT, where benefits realisation, risk and resource optimisation became futile.

From this perspective, the need to transform from Information Technology Governance (ITG) towards Enterprise Governance of Information Technology (EGIT) becomes understandable as it seeks to encourage desirable ICT behaviour by defining the holistic infrastructure for delivering ICT services from a company-wide governance perspective. In this, the bottom line seems to be the alignment of the business strategy with the IT strategy, outlining the roles and responsibilities of how IT-related decisions are made and overseeing regulatory concerns that affect the organisation to increase the overall returns on IT-enabled investments that promote overall growth and competitiveness within the organisation. EGIT considers risk management, alignment between business and ICT strategies, accountability, roles and responsibilities, and performance management to gauge efficiency and effectiveness.

From a higher education perspective, governance practices need to adhere to legislation such as the South African Higher Education Act of 1997 (South Africa 1997) and amended regulations to the act promulgated in 2014. In support of this act, it was found that under guidelines and policies prescribed within the KING IV Codes of Conduct and the Department of Public Service and Administration CGICT Policy framework, HEIs will, in future, be forced to transform from a "manage in isolation" perspective toward an enterprise-wide, holistic and inclusive governance perspective, inclusive of IT, as prescribed in "best practice" frameworks such as COBIT, TOGAF and ITIL.

Through evaluation, the COBIT 2019 Framework was found to be aligned to most other standards, frameworks and best practices[13] and provides a central mechanism for HEIs to govern and manage IT-enabled investments in support of organisational goals. Due to its alignment with existing standards and frameworks, COBIT 2019 is the most applicable framework to provide HEIs with a roadmap for implementing EGIT from within a holistic and organisational-wide strategic and broad governance perspective.

The COBIT 2019 Framework is currently the most applicable and conducive framework for meeting the legal requirements prescribed in the South African Higher Education Act of 1997 (South Africa 1997) and amended regulations of 2014.

[13] ISO (20000, 27001-5, 38500-2), NIST, CMMI, TOGAF, ITIL and KING IV etc

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