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Hardware Techniques to Mitigate Cyber and Data Thefts to Enable Digital Technology Adoption

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Abstract

Today, businesses can go a long way by leveraging virtual reality technologies complemented by the global outreach of internet. These technologies, also known as the metaverse, are basically a mirror image of any real-life product or commodity portrayed as a virtual 3-dimensional (3D) digital recreation that can be viewed by consumers on any smart device. This immersive 3D experience wherein consumers remotely from the comfort of sitting at their homes can visualize a physical product without the emotional touch or feel, opens potentially new realm for businesses. Some realistic examples being online shopping experiences created by IKEA for furniture 3D visualization, Sephora for virtual make up mirrors, Audi for a virtual selection of consumer dream car design attributes or modelling 3D views of sample houses; there are unlimited possibilities. Mushrooming closed circuit televisions (CCTV) at every nook and corner, in-car recording cameras and other lens-based video recording devices have already become a necessity today.

However, on the pretext of providing easy access, all these portals inadvertently capture, record and store huge amounts of consumer personal and commercial data. While Metaverse opens an exciting new realm for innocent gullible consumers, they may not be aware that this data can easily get stolen, hacked or sold if the portals are vulnerable to cyber security or data thefts. Today, India being the fastest growing market in the digital arena: development of digital platforms has outpaced the adoption or awareness of cybersecurity and data privacy. Recent cases such as cybersecurity data leak from prominent consumer electronics brand in India such as boAT or the breach of consumer data from Bigbasket exposes the vulnerability of these online portals to cyber theft. The Metaverse is a paradigm shift in digital interaction, offering businesses unimaginable opportunities for a collaborative, immersive, virtual reality, with global outreach. On one hand, this shift has snowballed into a rapid evolution of digital platforms while on the other hand it has introduced a complex threat landscape of cybersecurity and data privacy that significantly disrupts enterprise adoption.

This paper examines the threat vectors specific to devices in metaverse ecosystem, that include factors such as identity theft, compromised biometric credentials, smart device vulnerabilities and finally the biggest challenge posed by AI impersonation. Furthermore, in the context of persistent consumer geotags or sensor-based data collection; it analyses the regulatory gaps inherent in General Data Protection Regulation (GDPR) frameworks. This paper proposes onion-layered strategies to identify isolate-test-mitigate threats - with inner layer metaverse devices being in close proximity to humans and outer layer devices that surround us in the external environment. It highlights gaps in techno-commercial, infrastructural, organizational, and governance-level to recommend risk averse solutions. The outcome is

an 8-step framework mapped to Vulnerability- Uncertainty- Complexity- Authenticity (VUCA) based on the device threat impact score. This framework can be referenced by businesses to prepare a future-looking roadmap that will enable a stable, reliable and secure metaverse adoption.

Keywords: AI, AR/VR, Blockchain, Cyber, DSA, Digital arrests, GDPR, Metaverse, Security, Smart devices, VUCA

1. Introduction

The idea of Metaverse—a virtually passive and immersive, persistent and networked 3-dimensional environment—thought to be a fictional concept is rapidly transitioning to a realistically viable business platform. For both big and small enterprises, Metaverse is spearheading the creation of value, remote collaborative immersion, enabling virtual retail stores that can transcend global physical boundaries, to bring in innovative delivery models for education, shopping and healthcare [1], [8], [20]. By leveraging Augmented or Virtual Reality (A/VR) technologies, businesses and enterprises can generate digital twin models to enable import into industrial simulation tools or play host to global virtual for an immersive engagement [2], [8].

Although it looks promising, Metaverse has a “grey shaded zone” that presents significant hindrance to its widespread adoption to business. The infrastructure is naive and the techno-commercial environment is dominated by a "complex system" of intertwined components involving A/VR immersive headsets, nodes for edge computing as well as blockchain networks that are decentralized— each system and their interface presenting unique vulnerabilities and challenges [6]. Existing security walls are on the verge of obsolescence, still catering to traditional 2-dimensional environments with inherent vulnerabilities. These security walls render insufficient to the sophisticated and persistent nature of Metaverse threats [10], [14]. The seamless adoption of metaverse needs to address 2 key problems: first, the lack of standards and robust security protocols is creating a fragile and potentially risky environment; second, the unrivalled density of sensitive customer data collection and availability that includes real-time biometric credentials, social media, personal and behavioral data—violates customer privacy and escalates regulatory concerns [1], [12], [4]. The notorious digital arrests are the rotten fruits of cybercrimes that can easily exploit this freely available personal data with insufficient digital protection walls. Digital arrests are a real time example of convergence of the advancement in digital technologies to human vulnerabilities that are in a way linked to limitations of metaverse [13]. The need of the hour is to apply autoimmunity to cyber and digital systems by applying intelligence and AI such that the system itself “automatically” identifies, blocks and reports unauthorized access by cybercriminals to the investigation bureaus – a term rightly coined as “cyber autonomy” [11]. With increasing transition of businesses to digitalization platforms, reliance on Metaverse technologies and the exponential rise of collected data, it has become imperative to develop roadmaps for a safe and secure adoption of Metaverse. This will help to predict and navigate scenarios of identity theft, financial frauds, and AI-generated misinformation [3], [8], [10]. The objective of this paper is to provide a structured approach by analyzing these threat actors to enable secure adoption of metaverse by businesses.

2. The emergence of cybersecurity threats

The available attack surface for cybercriminals is exposed when Metaverse is used by businesses as innovative vectors are introduced that can exploit the inherent physical to virtual weaknesses as well as

target pseudonymity of digital assets.

2.1 Identity stealing

In the Metaverse arena, a consumer's digital identity is defined by his digital persona also known as tenacious avatar. Identity stealing or theft in this reference stretches beyond stolen credentials to include "avatar or persona seizing." Sophisticated attack mechanisms can mischievously steal motion data from A/VR headsets or seize network IP credentials to subjugate a customer's digital persona [8], [19]. The instant a customer's digital avatar is compromised, cybercriminals can easily login to perform fraud via social engineering or cause irreparable damage to the reputation of the individual or the business he may be representing [1], [16]. The impact of such an impersonation is psychologically more severe than the primitive online identity thefts due to the experiential nature of the A/VR or metaverse environment [16].

2.2 Biometric Credential Exposure

A/VR technologies potentially rely on a stable stream of data tapped from consumer biometrics to generate real time interactivity and motion. While streaming data, the electromechanical sensorial devices record highly sensitive consumer information that includes various facial expressions, voice and fingerprints, and even critical internal parameters such as heart beats, dilation of pupils or pulse rates [6], [14]. In contrast to our traditional passwords, the data captured using biometrics is rigid or non-volatile and cannot be erased. As such, any breach or compromise will pose permanent damage to the consumer's security, privacy becoming an imminent risk [1], [2]. This "digital ID" which is a virtual biometric footprint leaves the door open for attackers who can easily exploit this potentially weak physical to virtual link thus violating the main attraction of immersive technologies [2], [14].

2.3 Digital Prying

The use of camera and lens technology has exponentially amplified the violation of personal data. With network connectivity, semiconductors and IP within these devices; technology has in fact made consumer data more vulnerable [20]. Smart home gadgets such as Amazon Alexa, Apple HomeKit and Google Home are new "addictions" that make consumer lives convenient while compromising on privacy. Internet driven remote controlled heating, lighting, baby or pet monitoring, refrigerators, ovens, washing machines are other smart home devices that inadvertently record private user data on a 24x7 basis [5]. Virtual economy-driven management of digital assets and Non-Fungible Tokens (NFTs). are extensively dependent on blockchain technology backbone that is susceptible to exploitation due to bugs in the coding architecture [8].

2.4 Media synthesis

Use of GenAI for Metaverse has given birth to the phenomenon of "deepfakes." Hackers can tap readily available image, audio, video files from internet and utilise advanced Generative Adversarial Networks (GANs) or Convolutional Neural Networks (CNNs) to develop fake audio/video streams that imitate real life and have become indistinguishable [8], [10]. These fake profiles are then used as proxy pathways to penetrate virtual meetings as someone else, spread hoax or rumours, and instigate frauds [3], [10]. Such manipulated media can violate IP rights and easily harm company or individual reputation [20].

3. Privacy and regulatory challenges

Metaverse provides heavily data dependant high fidelity immersive experiences is that eventually creates a "privacy enigma" as it requires collating enormous personal, social and environmental data.

3.1 Regulatory Landscape: GDPR and the AI Act

The regulation of metaverse is most stringent using European laws. In context to virtual reality realm,

permission for data retention and by default right to data erasure after usage should be a mandatory approach dictated by the General Data Protection Regulation (GDPR) rules [17], [21]. There are key guidelines provided by EU AI Act as well as the Digital Services Act (DSA) on identifying the risks and hazards of AI interactive actions and dealing with them responsibly [1], [21]. The major hindrance to this adoption is the cross-country regulatory conflicts and expenses which is a part and parcel of the global nature of Metaverse. The compliance expenses and ownership have been a major blocker to bringing in innovation in this context.

3.2 Collating Data and Behavioural Profiling

As Metaverse is ubiquitous, it can easily record and retain track of user interaction to different virtual realms. This gives rise to a 24x7 live and "enormous quantum of human sensorial data collection," via platforms leveraging multiple channels that was unfathomable before [19], [24]. This enhances creation of detailed user profiles embedding personal preference, social interaction, networks and geographical movements [1],[7]. This enhanced user profiling is a potent leak of privacy as user anonymity is easily compromised thus exposing their social preferences and networks. Companies need to take responsible decisions based upon the fact that user personalisation for marketing gains does come at the cost of unethical, immoral and intrusive user monitoring [16].

3.3 Privacy invasion by user sensorial data collection

A/VR and Metaverse has a critical privacy problem due to "sensor-based data collation" that is a persistent “global” digital record that extends beyond the boundaries of regular digital footprints. Wearable technologies remain close in contact to human body and are persistently collating as well as recording data over cloud, thus exposing the gullible user to a myriad of cyber hazards instead of making him feel safer and secure. Once the data is posted to cloud, without even connecting to these sensors; the users’ vital and sensitive parameters become accessible remotely on-the-go, their environmental surroundings, geolocation, proximity to political persona can easily be monitored leading to catastrophic scenarios [14]. Have your ever imagined that the electronic toys that your kids are addicted to can easily be hacked into and transfer your privacy to the dark world! This privacy invasion without an informed agreement is potentially alarming [6], [14]. Wont it be scarier if someone anonymous in future can remotely access and control your heartbeats by hacking into a pacemaker! Today the hacking and breaching of these advanced technologies have outpaced the development of security and protection mechanisms of the technology itself. Technology must be “auto-immune”, “auto-shutting” and “auto-correcting”, else the so-called hype around AI being smart is worthless!

3.4 Regulatory gaps

The biggest challenge for organizations is that there are no common platforms that offer privacy and security. The solution to this is via international think tank collaborations that will enable creation of global governance frameworks and interoperability standards [1], [12], [18]. With potential regulatory voids and limited standards, the rules to protect IP and data related to metaverse is the core challenge in their adoption by businesses [20].

4. Multipronged mitigation strategies for building resilient business

To enable trust and foster secure metaverse adoption, a multi-pronged mitigation strategy needs to be implemented by businesses that amalgamate techno-commercial, governance and organizational- level controls.

4.1 Techno-Commercial Solutions

- **Identity based authorized access Management**: Implementing password protected authentication, blockchain-based "Self-Sovereign Identity" (SSI) systems layered with multi-factor authenticated (MFA) protection will isolate and encapsulate digital personas from unauthorized usage [1], [2], [3].
- **Building a Zero Trust Architecture (ZTA)**: Adopting a ZTA model which limits access to "just nice and minimal" as well as iteratively verifies identity [8], [9].
- **Anonymity and data encryption**: Embedding application-layer with encryption and Privacy Enhancing Technologies (PETs) to mask biometric and other sensitive personal data [1], [2], [6].
- **Smart detection using AI**: Exploiting AI technology to proactively detect real time threats, anomalies or hazards and cut off or boost auto-immunity of the systems to drive self-correction mechanisms [8], [10], [19].
- **Smart alarming using AI**: AI technologies should also be enhanced and used to geo-track and locate the attackers in real time, raise alarms as well as auto-share IP addresses with regulatory authorities, and cybercrime cells to immediately spot the light on the threat vectors
- **Smart devices**: Calibrating and teaching smart home devices to filter and identify various threat patterns, auto-recognize, isolate and flag alarms that will act as deterrents [1], [3], [8].

4.2 Governance Controls

- **Inherent design privacy**: Implementing minimalistic data collection, localized processing, zero data storage and mandatory erasure of biometrics to ensure privacy as a foundational element of metaverse systems [1], [2], [9].
- **Global Participation and agreements**: Engaging in initiatives that are cross-industry to develop interoperability agreements, unified and structured data formats as well as security standards [1], [20].
- **Policy and governance restructuring**: Formation of internal review committees encompassing think tanks across the governments to define the ethical usage of AI and oversee its honest implementation [7], [9].

4.3 Organizational Practices

- **Integration of DevSecOps**: Integrating security and privacy weaved across the entire lifecycle of metaverse application development [7], [21].
- **User training and education**: Providing in-depth training to consumers, employees as well as shop floor staff to be at par with the risks of social engineering, digital prying, persona hijacking, phishing and data theft hazards while using immersive environments [1], [2], [16].
- **Applying Cyber and Forensics to Virtual platforms**: Establishing process and protocols to audit, manage and investigate digital platforms security breaches by applying auditable logs, access tracking and virtual forensics [4], [19].
- **Risk and Crisis Management**: Mitigate the negative impacts of data leaks on brand trust and reputation by planning, implementing, and consistently developing reputation-protection plans [19].

5. The 8-Secure closed loop steps mapped to VUCA for a successful metaverse adoption

The successful adoption of metaverse by businesses will need a streamlined, structured, proactive, predictive and risk-averse or auto-risk mitigating roadmap that will eventually ensure security and privacy are fundamentally rooted at every stage of the lifecycle. In order to baseline this, the following 8-step framework categorized shown by *Figure.1* into a Vulnerability, Uncertainty, Complexity and Ambiguity (VUCA) matrix as shown by *Figure.2* is a recommended approach to alleviate the root cause.

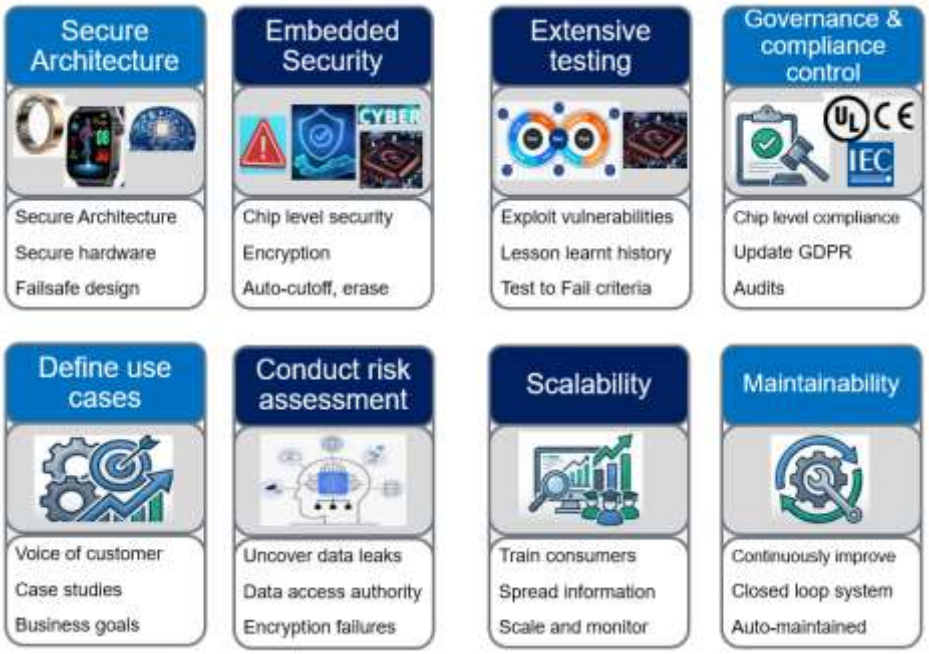

Figure 1: 8-Steps for a successful metaverse adoption

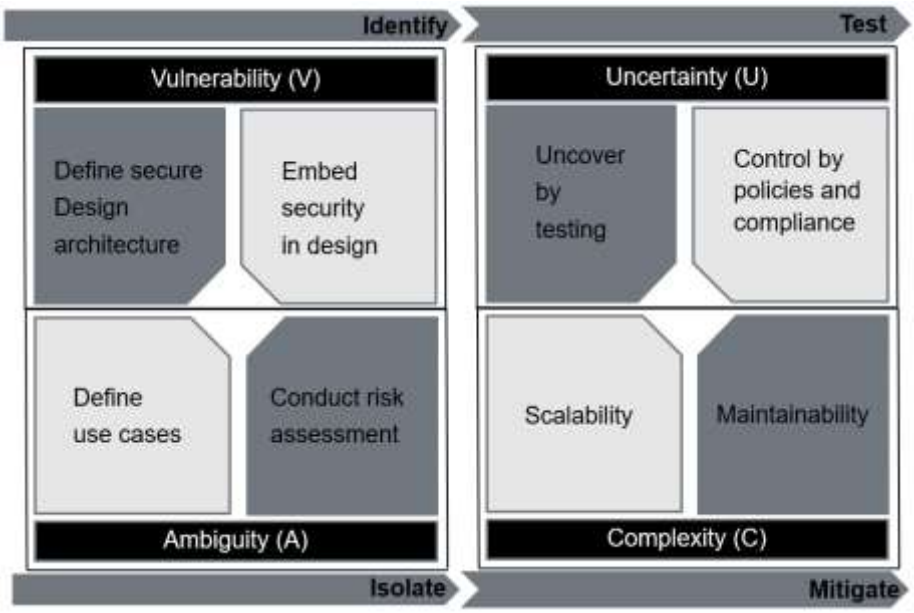

Figure 2: The 8-Step Framework mapped to VUCA for successful METAVERSE adoption

5.1 Vulnerability (V)

Step 1: Define a secure chip design architecture (DcSA)

Businesses should opt for platforms that support interoperability and low-trust interactions. The network topology must be designed to accommodate the low-latency requirements of 5G/6G while maintaining secure, encrypted channels [2], [15]. Today this feature is only available in the high-level apps defined as software package while the hardware chip on the device itself has vulnerabilities. The architecture of the chip should be futuristic to embed security within its core – a standalone failsafe architecture.

Step 2: Embedded Security

At the design phase, smart metaverse devices should integrate technical controls that include authemtica-

tion, encryption, data compression, auto-timed deletion, on-chip biometric processing, and auto cutoff as well as intrusion detection alarm generation. The goal is to eliminate the threat at device or chip level instead of relying on software that may need intermittent patch updates. Ensuring localized content protection for digital assets and devices near humans will help prevent IP and information theft [1], [2], [3].

5.2 Uncertainty (U)

Step 3: Implement Testing

Rigorous testing should be a routine process which will be used to uncover deep hidden vulnerabilities. While DevSecOps is a high-level testing method, it fails to penetrate chip level. The chips within smart devices should be capable of routine auto-testing to keep itself immune from threats – known or unknown. Chip design development cycles should include security testing and threat modeling as a real time continuous process. With multiple-core chips this is a no brainer and can be easily implemented. Advanced methods of virtual-forensic capabilities should be implemented within the chip that will ensure that any attack incidents can be logged and effectively investigated [19], [21].

Step 4: Governance and Compliance Controls

Minimum Viable Prototype (MVP) and limited pilot builds need to be implemented to test the design robustness before full-scale deployment. This will validate incident response protocols and confirm that the architecture aligns to GDPR or the EU AI Act [1], [2]. In addition, regulatory testing governed by agencies such as UL, CE as well as IEC will enable further global compliance at chip level.

5.3 Complexity (C)

Step 5: Scalability

As the secure chip designs scale to production mode, businesses must embed AI-driven detection to identify system level anomalies. Random user test cases need to be deployed to introduce environmental challenges such as usability, pressure, temperature, or sample variations. In parallel, users need to be continuously trained to keep them abreast of the threats, their feedback taken to close the loop and improve the design further which is essential to sustain their trust and eliminate social engineering threats [1], [2].

Step 6: Maintainability

The metaverse ecosystem is naïve and as such its surrounding threat landscape is also evolving rapidly. Continuous monitoring as well as updating chip level threat models, audit of design-test strategies to ensure compliance with emerging global standards and regulations is a basic need [1], [12]. In fact, the microchips being used in metaverse ecosystem should have cybersecurity hardware component as a real time independent watchdog.

5.4 Ambiguity (A)

Step 7: Clearly define the requirements, objectives and user scenarios

Businesses need to clearly breakdown their business goals and focus areas – whether to cater to external customers, internal team or staff collaboration or if the purpose is to perform an industrial stress simulation. This will help to define the acceptable risk tolerances and plan various mitigation strategies. Voice of customer (VOC) surveys, case studies, user scenarios, lessons learnt based on historical data leakage records, traceability, competitor benchmarking as well as possible mitigation scenarios need to be formally documented to identify gaps and create innovation opportunities.

Step 8: Conduct Privacy, Risk and Vulnerability Assessment

A comprehensive assessment needs to be conducted that will map all data flows covering internal and external paths, sensor attachments and integrations, and lastly virtual interface exposures to user

applications. This step identifies and prioritizes the potentially vulnerable high-risk assets, such as sensitive biometric data of users or intellectual property (IP), aligns to the threat scoring and assesses the impact to develop automated self-defensive solutions on chip [2], [7].

Onion layer	Device in Metaverse ecosystem	Proximity score based on human/ pet body contact (P) 5(High) - 0(Low)	Severity score (S) 2(Major) - 1(Minor)	Device Technical Vulnerability score (V) 5 (High) - 0 (Low)	Threat & Impact (I) Score (P) x (S) x (V)
0	Smart finger rings, Smart watches, Neural microchips, Pacemakers, Helmets, Hearing aids,	5	2	5	50
0	Baby monitoring, Pet collars, Smart garments, Smart geo-tag sensors,	5	2	5	50
0	Home based diagnostic monitoring devices- Temperature, Glucose, Blood pressure, BMI/Weight	5	2	5	50
0	Wireless earpods, Smart glasses, Smart toys, Smart cameras	5	2	5	50
1	Smart phones, Laptops, Printers, Scanners	3	1	2	6
1	Smart TV, Soundbars, Gaming, AR/VR/MR, Smart mirrors,	2	1	2	4
1	Smart fridge, Smart oven, Smart washing machine, Robot vacuum cleaners, Smart thermostats, Airconditioners, Water filters, Smart keys	2	1	2	4
1	Security cameras, Smart speakers (ALEXA), Smart apps, Smart meters	2	1	3	6
2	Cars/EV, E-bikes, CCTV, Elevators, In car electronics Digital locks	2	1	4	8
2	Digital assets, Blockchains, NFT, Data centres E-lockers	1	2	4	8

Table 1: Onion layering of metaverse device to calculate threat scores

6. Conclusion

The devices in metaverse ecosystem offer a profound potential for future business transformation, however this potential can only be realized positively if the accompanying cybersecurity threats and data privacy exposure risks are managed locally and effectively. The everyday emergence of novel requires a departure from traditional security thought process being applied at the highest application level but needs to be instead embedded to the device hardware. This localized intelligence will help to build a more proactive, resilient, multi-layered, self-sensing, self-defensive, self-isolating and alarm generation strategy. By adopting frameworks that rely on device hardware concurrency, low latency, fast operation and decision, as well as fast turnaround times the key gap in the existing governance and compliance rules can be plugged in. This will introduce another ring of security instead of just relying on the top-most software-based application layer. A total reboot of the thought process to make the lowest vulnerable level inherently robust to threats is what is the need of the hour. The recommended 8-step framework combined with VUCA and superimposed over the measured threat scores referencing *Table 1* will provide a strategic starting point for organizations that can help navigate the complexities of this new digital frontier while safeguarding human capital, assets, and customers at device level (as shown in *Figure 3)*.

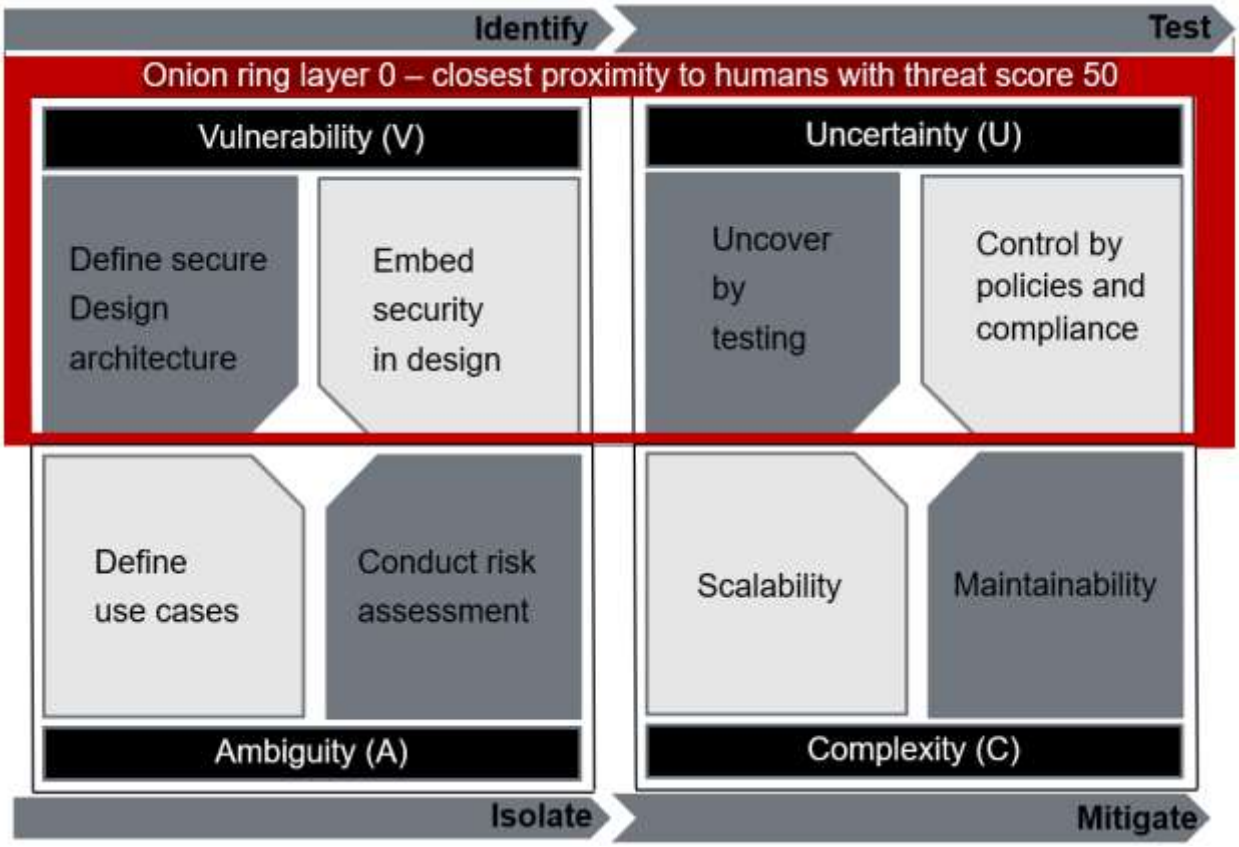

Figure 3: Mapping VUCA-8 Step metaverse framework to threat analysis.

Author contribution	Writing – original draft, verification, publish manuscript
Informed consent	The literature review was conducted based on available literatures from arXiv, IEEE, Scopus and other renowned literature databases. There was no human participant involved in the development.

Data Availability	The data used and presented in this review is available from various literature libraries
Conflict of interest	The author declares no conflicts of interest
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