Technical Report: Essential Development Components of

The Urban Metaverse Ecosystem

Kaya KURU[1]

[1] School of Computing and Engineering, University of Central Lancashire, Preston PR1 2HE, U.K.

Abstract

Urban metaverse shared worlds, an extension of residents and urban society, where the virtual and the physically real blend and are more organically integrated, would impact urban ways of living significantly with many practical implementations. This would open doors for potential businesses with tremendous global economic value by democratising skills/assets within an urban environment. In this treatise, while the urban metaverse ecosystem is flourishing, this technical report analyses essential components in developing urban metaverse cyberspaces.

Keywords: Metaverse, smart city (SC), Digital Twins (DTs), avatars, blockchain, Augmented Reality (AR), Virtual Reality (VR), Web 3.0, web3.

1. INTRODUCTION

Recent advances in metaverse technologies are providing many opportunities and urging city governments and all other stakeholders within an urban life to change the way of managing cities and doing business more intelligently in location and time-independent, high-fidelity virtual worlds [1] to alleviate the problems of rapid urbanisation (e.g. increasing population, pollution, traffic, noise, real-estate/office prices, and mobility difficulties) with limited urban resources, by overcoming temporal and spatial restrictions.

1.1. Metaverse

A metaverse can be defined as ``democratised, decentralised, user-driven virtual and augmented immersive 3D spaces where two worlds -- virtual and physical existence -- can be more tangibly connected and people who are not in the same physical space can come together with their avatars to feel many different types of experiences''. The metaverse -- a blended harmonised virtual and physical existence -- aiming at developing high-fidelity virtual worlds as rich as the real world, is still in its infancy, requiring a great deal of evolution. First and foremost, open-source metaverse development platforms are in high demand and they are expected to expedite the development of many undiscovered metaverse experiences.

2. ESSENTIAL COMPONENTS OF THE URBAN METAVERSE ECOSYSTEM

The key components of the metaverse in developing urban worlds are shown in Fig. 1.

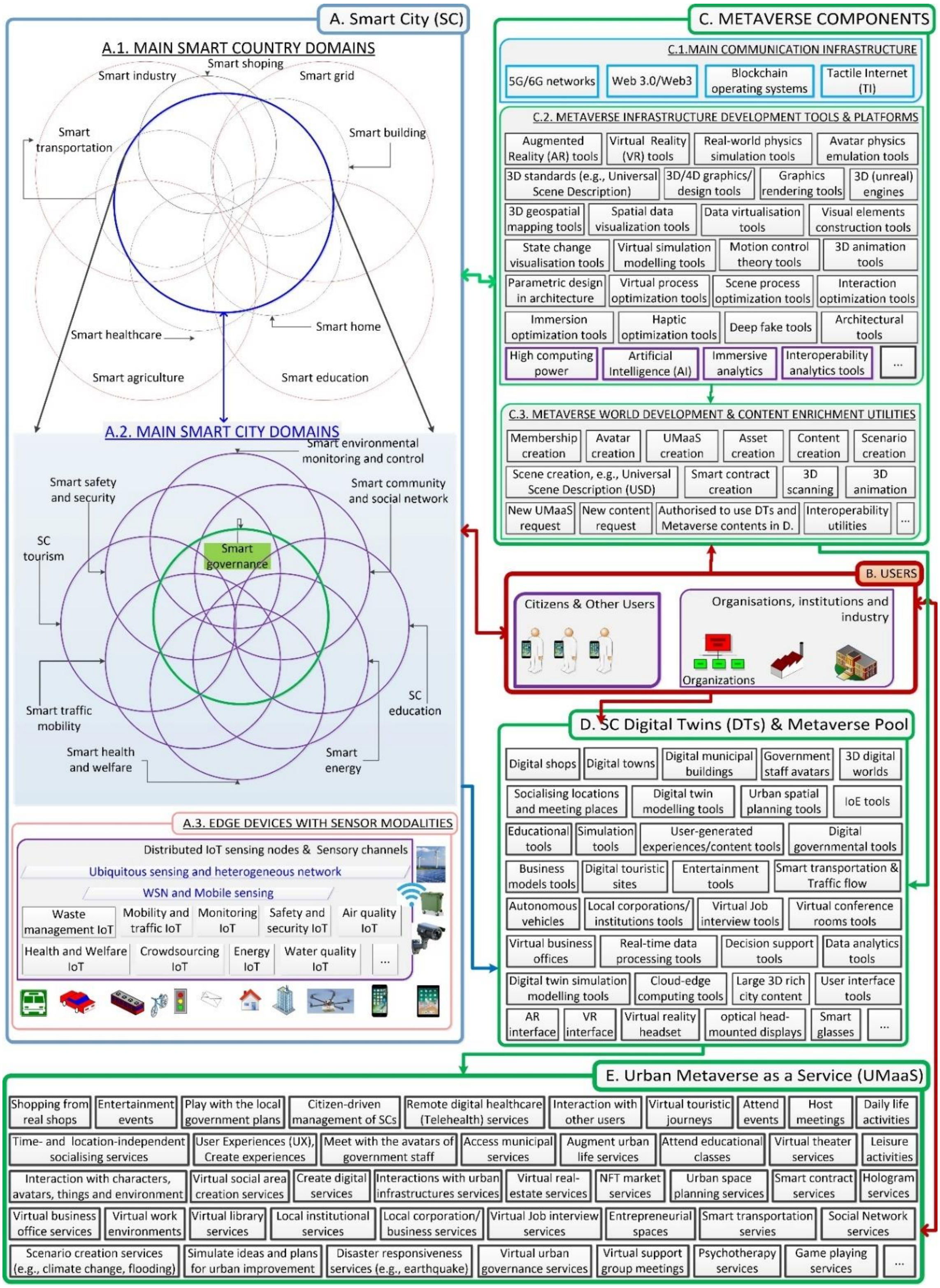

Figure 1: Architecture of a metaverse city: Main components and their interaction with each other [1].

2.1. Smart Cities

The granular components of the SC and their interactions with one another are depicted in Fig.1. A. The concepts of Internet of Everything (IoE) and Automation of Everything (AoE) [2] bring the people, organisations, lives, processes, data, and things into a concrete coherent structure -- Cyber-Physical Systems (CPSs) to develop a synergistic smarter connected globe [3]. The main objectives of establishing SCs can be summarised as i) enabling the integration of the distributed services and resources in a combined synergistic fashion, ii) improving existing public services and providing new effective citizen-centric, user-driven, and demand-oriented services, iii) monitoring a city with easy-to-use visualisation tools, iv) enabling near-real-time services for end-users and/or further smart actuation, v) increasing the sustainability with optimised services, vi) improving the lives and livelihoods of citizen, and vii) drive economic development, innovation and global city investment competitiveness [3]. Readers are referred to [3] for the technological infrastructure of SCs involving communication networks and further information about real-world SC use cases. To summarise, its main layers enabling proper sensing and appropriate autonomous actuation are i) strict engagement with all the stakeholders, ii) edge IoT devices and citizens to collect data and interact with the environment intelligently by harnessing large amounts of near-real-time data using sophisticated communication technologies, iii) edge/fog platforms, iv) the cloud platform involving cloudlets, and v) integration of smart domains not only within itself but also with the national and global smart domains. The main smart elements of SC are shown in Fig.1 A.2. The other smart domains into which SC (Fig.1 A.1) is incorporated to create a synergistic implementation enabling a gate to the development of a group of SCs and consequently smart states and smart countries are explicated in [3] as well. The development of DTs is an indispensable part of establishing SCs.

2.2. SC Digital Twins (DTs)

The success of urban metaverse applications depends on the quality of data-driven SC data, the seamless exchange of this data and the processing of the data effectively and efficiently. To this end, the construction of DTs, i.e., blueprints of SCs, that facilitate the means to monitor, understand and optimise the functions and Situational Awareness (SA) of all physical entities by i) pairing of the virtual and physical worlds [4], ii) enabling data to be seamlessly transmitted between the physical and virtual worlds with two-way communication [5] and iii) enabling the virtual entity to exist simultaneously with the physical entity [6] is an integral part of building healthy SCs and granular metaverse worlds augmented with real-time streaming data. SCs, filled with ubiquitous sensors (Fig.1 A.3), ease the detection of real urban environments and they stream this information simultaneously to build urban DTs for accurate topography, visualisation, simulation, anticipation, precise interpretation and predictions, and solving urban problems with innovative eco-friendly ways of urban planning benefiting the well-being of citizens. Examples for DTs are displayed in Fig.1. D. DTs are tied to their physical counterparts in real time to automate tasks and extract wisdom/insights that can increase the quality of citizens' lives. Although the metaverse concept existed 10 years before the emergence of DTs, it is still in the concept stage, and DTs have been widely utilised in industries and other fields [7] given the broad scope of DTs. SCs have been building their DTs (i.e., virtual replicas) of the physical city implementation infrastructure using their technological infrastructure and real-world SC domains using CPSs. DTs of physical worlds would be the base for developing ultra-realistic metaverse worlds. The more advanced immersive technologies such as TI with quality haptic feedback, the better immersive urban metaverse worlds using urban DTs leading to better SC services. The concept of the metaverse with its advancing immersive tools would not only enable the development of the realistic modelling of urban processes as they behave in their physical worlds, but also, it would encourage and accelerate further community engagement by addressing user requirements better leading to more advanced models.

Most of the cities have their multiple 3D models involving underground infrastructure used for planning and construction and these models are categorised as ``(high-fidelity virtual) SC physical worlds (twins)'' and this should not be confused with ``SC DTs''. Highly realistic ``SC DTs'' (i.e., models) are composed of synchronised ``(high-fidelity virtual) SC physical worlds (twins)'' and related delay-sensitive ``SC digital data twins'' (Fig. 2) allowing residents and other users to interact with the virtual SC ecosystem that is created similarly to the real SC ecosystem. In other words, 3D models of SC objects or SC environments (buildings, streets, roads, walkways, etc.) that represent the body of a system (i.e., virtual clone) are combined with their related streamed data that represent the instant dynamics/activities in the body not only to build more realistic systems, but also to make user interactions more realistic. Real SC data is continuously streamed into the data-driven SC DTs simultaneously as in the real SC environment, which makes the interaction feel the same as interacting with the real SC environment. One example of the SC DTs is investigated in my previous study in [8], [9] for the urban use of Autonomous Vehicles (AVs). In that research, Human-on-the-loop (HOTL) real-time haptic delay-sensitive teleoperation with AVs is analysed in the aspects of human-vehicle teamwork by establishing two similar remote parallel worlds -- real-world vehicle time-varying environment and cyber-world emulation of this environment, i.e., -- in which a Human TeleSupervisor (HTS), as a biological agent, immersed with the absence of cybersickness enables omnipresence through a timely bidirectional flow of energy and information. Again, in my another previous study in-[10], the roads of Preston city were designed in 3D forms and a DT was created by streaming the traffic flow data into this high-fidelity virtual DT. Drivers in the city can observe the live traffic at any point by interacting with these points in more realistic 3D environments and can choose their most convenient route to their destination based on the visual traffic volumes and congestion patterns. SC DTs are the building blocks of urban metaverse worlds. The recent advances in the cyber–physical domains, cloud and edge platforms along with advanced communication technologies play a crucial role in connecting the globe more than ever, which is creating large volumes of data at astonishing rates and a tsunami of computation within hyper-connectivity [11]. Large volumes of BD being generated exponentially in different formats are in the geo-distributed cloud platforms and likely input for all other smart systems and enterprises as insights, which will contribute to the smooth working of these systems and enterprises substantially [11]. Many of the potential urban metaverse worlds are yet to be discovered and developed and the ready-to-use off-the-shelf SC twins and newly built twins are expected to expedite the development of more resilient metaverse implementations in the SC ecosystem.

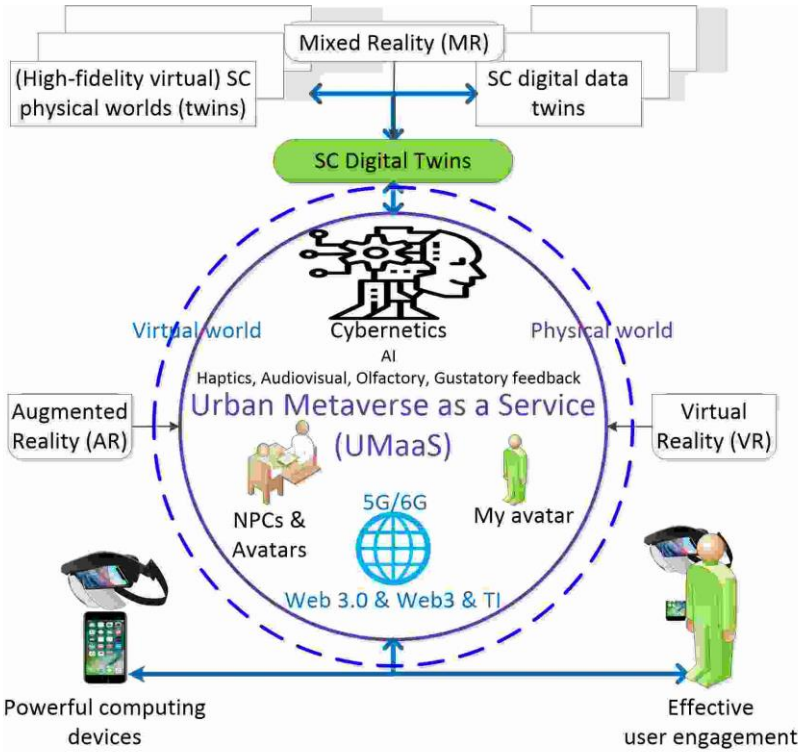

Figure 2: Pivotal components of UMaaS. Blurring borders between virtual and physical worlds.

2.3. Urban Metaverse as a Service (UMaaS)

UMaaSs are the fragmented worlds of the urban metaverse ecosystem. The driving components of UMaaS are depicted in Fig. 2. UMaaSs are parallel urban rooms, allowing the efficient customisation of particular urban metaverse services. The main building blocks in establishing UMaaSs -- moulding the physical world and virtual world within an intertwined environment-- are cybernetics, avatars, assets, non-player characters (NPCs) and SC DTs. Granular UMaaSs provide residents with specific immersive shared observations, interactions, collaboration and social experiences via well-designed user interfaces leading to high QoE. The generation of granular UMaaSs would reduce required computing resources at a time significantly. UMaaSs, with rich activities, are the multiple urban metaverse worlds, i.e., co-existence and co-dependence between the physical world and the virtual world. UMaaSs, tailored and enriched with individuals' experiences using AR and VR tools, aim to eliminate the boundaries such as time, space and language between real worlds and their immersive counterparts. Teleoperation between UMaaSs is possible to complete various specific tasks. Examples of UMaaSs are displayed in Fig, 1 E.

2.4. Urban Metaverse communication infrastructure on a decentralised network

The engines of the metaverse communication infrastructure on which metaverse applications can run seamlessly are placed in Fig. 1 C.1. The foundational pillars of this infrastructure are 5G/6G networks, Web 3.0 / Web3, Blockchain operating systems and Tactile Internet (TI). The communication infrastructure in cities to establish SC applications has already been analysed in my previous research [3], [10], [11], [13], [14], [15]. Therefore, this subject is not elaborated in this technical report and the readers are referred to these studies about the communication technologies employed in SCs. To summarise, city communication infrastructure provides large-scale machine-type communications with a multiplicity of communication modalities using an orchestration of backhaul and fronthaul (i.e., crosshaul) mechanisms. Instant feedback through the metaverse technologies (e.g., high-definition (HD) rendering, smart wearable devices, haptics (tactile and kinesthetic) (sense of touch), audiovisual modalities, olfactory (sense of smell), gustatory (sense of taste)) is going to play a pivotal role in establishing a strong immersive metaverse implementation that enables a tight interface between the physical and virtual worlds by coupling with artificial sensors and actuators.

User-centric and decentralised Web 3.0, with rich media content, semantic immersive UX and AI capabilities, has changed our communication and interaction behaviours significantly compared to one-way text-based Web 1.0 and ubiquitous vision-based user-driven Web 2.0. Furthermore, the incorporation of blockchain technologies into Web 3.0 has created a more evolved decentralised web -- Web3. Web3, using multiple operating systems, provides data sovereignty (e.g., creative asset sovereignty) for individuals allowing a more advanced user-centric decentralised network with further individual data management capabilities. While 5G technologies are taking their indispensable places in real-world implementations, it is worth mentioning that future 6G, at the expense of increased complexity, considers not only delivering another 1000x increase in data rates, but also diving into self-sustaining networks and dynamic resource utilisation; 6G will also put an end to smartphone-centric networks, introducing new system paradigms (e.g., human-centric services) [16]. 6G, not only promises to connect things with URLLC (1-microsecond latency) leading to no delay in real time, but also promises to connect things intelligently with ultra-high density connections (i.e., over 100 devices per cubic metre). In this sense, the use of location awareness immersive technologies, AR/VR/XR/MR as well as holographic communication, will be eased with 6G since intelligence, as the key component of immersive technologies, is connected. The combination of blockchain and 6G allows the streamlining of a peak rate of 1 Tbit/s [17] using a Terahertz-sized frequency band to achieve a network delay with a transmission rate of less than 1 ms and the probability of communication interruption less than one in a million using spatial multiplexing technology [18] and many SC initiatives are very much familiar with Web3 by using blockchain technologies for their various applications.

2.5. Metaverse infrastructure development tools and platforms

The elements of the metaverse infrastructure building tools and platforms are placed in Fig. 1 C.2. Some of these tools and platforms are AR/VR, real-world physics simulation, avatar physics emulation, open source 3D standards (e.g., Universal Scene Description), 3D/4D graphics/design and rendering (e.g., Unreal Engine), 3D geospatial mapping and visualization, state change visualisation, virtual simulation, motion control theory, and optimisation. The targeted outcome of these tools can be shaped with AI, immersive analytics, and most importantly interoperability analytics tools to yield platform-independent products using high computing power. These tools and platforms are still being developed. They need to be advanced further and need to be readily accessible to the engineers in the metaverse development community at affordable prices. These tools and platforms can only be developed by a group of engineers from different disciplines and they are required to enable trained engineers to deploy ``Metaverse world development and content enrichment utilities'' which are demonstrated in Fig. 1 C.3 and elaborated in the next subsection. No single company has sufficient resources to create these tools alone on a wide scale since the rich diversity of these technologies requires multiple technology companies to mould their expertise in an advanced metaverse infrastructure development platform. Companies from various disciplines with varying skills and a rich variety of enabling technologies need to collaborate to build advanced metaverse development platforms using a broad amalgamation of advanced technologies leading to an increase in impressiveness.

2.6. Metaverse world development and content enrichment utilities

The elements of the metaverse world development and content enrichment utilities are placed in Fig. 1 C.3. Some of these utilities are avatar creation, UMaaS creation, asset creation, content creation, scenario creation, scene creation, smart contract creation, and 3D scanning and animation. The members of UMaaS worlds are authorised to use DTs and metaverse contents that are already created and shared as depicted in Fig. 1 D. Trained engineers, people and residents can create and enrich metaverse urban worlds with high-fidelity rich content and experiences representing real-world services using these easy-to-use utilities with functional interfaces requiring no high-level expertise. For instance, current AI technologies such as Ready Player Me/OZ, Unreal Engine, Nvidia, and Microsoft Mesh’s Holoporation enable to generation of hyper-realistic avatars.

3. DISCUSSION AND CONCLUSION

The metaverse, aiming to accommodate a large number of real-time immersive interactions, opens a new era of urban development, urban living and urban business, enabling a more sustainable future for urban life. The near future will embrace more metaverse applications fuelled by more advanced metaverse technologies leading to a change in the way of doing business in the urban ecosystem. This technical report analyses essential components in developing urban metaverse cyberspaces to direct researchers in developing their ideal urban metaverse development frameworks.

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