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Technological advancements and the vision of a meta smart twin city

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ABSTRACT

Recent digital advancements have led the construction industry to reassess its core principles. Critical issues such as construction site impacts, aesthetics, methodologies, and sustainability are under rigorous scrutiny. The challenges hindering the digital transformation of construction remain unclear. Addressing the technical questions of when, where, why, and how the industry is evolving is crucial, especially as digital operations become more prevalent compared to traditional methods.

The "digital twin" concept has emerged as a key approach in shaping the industry's future. Integrating Building Information Modelling (BIM) with the Internet of Things (IoT) has enhanced project engagement, though challenges persist. Traditionally, a digital twin represents the construction process and its interactions. But it misses the transactional and experiential aspects that integrate users into the process. Technologies like blockchain and the metaverse, combined with the digital twin, offer insights into the future of construction projects. Municipalities that adopt digital twins and metaverse representations of their commercial activities throughout construction phases are likely to set future standards for societal specifications.

As some specifications such as architectural designs should be grounded in the diverse aspirations and experiences sought by citizens. This paper aims to explore the ways digital twins, smart urban environments, blockchain technology, and other reality capture datasets contribute to the vision of digital and physical construction domains. It examines the interaction and convergence of new spatial constructs, highlight the critical role of data acquisition technologies, and present a comprehensive framework for user experience and the future of Meta Smart Twin Cities.

1. Introduction

After 2020, urban areas in both developed and developing countries have faced severe and complex challenges. These challenges encompass sustainable development, efficient resource management and technological integration. Notably, persistent issues such as climate change, water and food supply shortage, geopolitical conflicts and pandemics continue to affect urban life although the adoption of technology in society has been imminent. Efforts to tackle these challenges and problems have involved the pursuit of a unified intelligent urban environment which has uncovered significant deficiencies in current urban management, particularly in establishing a comprehensive digital representation of cities' historical, current, and future dynamics. These gaps include insufficient ideological alignment across regions, a lack of systematic top-level design and planning, and ongoing challenges in information sharing. Furthermore, vulnerabilities in information security, a scarcity of technical innovation expertise, limited social engagement, and fragmented development exacerbate these issues. Finally, inadequate policies for disaster management, such as handling pandemics and virtual reality education, fail to adapt to new interactions and innovations within digital spaces.

These shortcomings underscore the inadequacy of traditional urban planning and management practices, which not only constrain but also, to some extent, impede technological advancements and the evolving needs of urban populations, hindering their adaptation to the pace of technological advances. Moreover, contemporary literature has extensively addressed the problem statement of integrating advanced technologies such as digital twins and the metaverse in the smart city strategy into urban development. However, there are additional variables that have not been considered, which are essential for achieving sufficiently effective outcomes.

Key studies have employed various methodologies, including qualitative case studies and quantitative data analyses, to explore the impacts and challenges of these technologies. For instance, some investigations

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have highlighted the improvements in urban planning, optimize asset management and create secure, sustainable cities after disasters [1,2]. While other studies provide a framework for integrating smart city technologies with existing infrastructure [3,4]. Further integration of digital twin and metaverse technologies in urban environments, as seen in Seoul, Helsinki, Catalonia, Barbados, London, New York, Santa Monica, Shanghai, Singapore, Dubai, and Benidorm, demonstrates significant benefits and notable gaps. These technologies allow for immersive virtual experiences, efficient urban planning, real-time traffic management, enhanced public services, and innovative tourism promotion. Interesting cases to examine are the Helsinki's digital twin offers virtual tourism and civic services, while Singapore's Virtual Singapore enables comprehensive urban simulations for disaster management and infrastructure optimization. Barbados' metaverse embassy exemplifies new diplomatic avenues and cultural diplomacy, and London's 3D digital platform facilitates rapid, cost-effective construction planning [5].

However, the absence of a unified framework for these technologies leads to several gaps. Disparities in technological adoption and language barriers, as seen in Catalonia's CatVers, limit accessibility and user engagement. Regulatory hurdles, substantial initial investments, and the need for workforce skill development pose significant challenges to the seamless integration of these technologies. Additionally, ethical considerations, such as data privacy and security, remain inadequately addressed across different implementations. The lack of interoperability between various digital platforms, as highlighted by Barbados' ongoing development of a "teleporter" for avatar transport, underscores the need for standardized protocols and cohesive strategies.

Therefore, without a unified framework, the full potential of digital twin and metaverse technologies remains untapped, particularly in addressing future crises like pandemics. By integrating these tools, governments aim to enhance their capacity to predict, educate, and effectively monitor human behaviours. This approach not only aims to improve urban resilience and sustainability in an increasingly digital and interconnected environment but also serves as an initial step for countries considering less dense interaction realities in preparation for potential future disaster events and improving commerce behaviours.

The concept of a "Meta Smart Twin City" represents a potential solution by leveraging digital twin methodology to create a dynamic, real-time representation of urban environments by adding transaction within it through a metaverse. However, the implementation of the Meta Smart Twin City raises significant ethical, social, and technical challenges that must be addressed to ensure its effectiveness and sustainability. Therefore, the aim is to explore challenges, identify gaps in the current literature, and propose strategies to overcome them, thereby contributing to the development of more resilient and adaptive urban systems.

2. Background section

2.1. Research context - strategies of industry 5.0 and socieciety 5.0

The national strategies in developed countries such as Industry 5.0, Society 5.0, and others have been significantly providing a pathway to innovate many industries by disrupting their workflows or integrating novel methodologies within. In Germany, the concept of Industry 5.0 is defined by its ambition to delineate a clear distinction between spiritual beings and robots, thus propelling advancements in Artificial Intelligence (AI) and robotics in the manufacturing industry. Moreover, Industry 5.0 places significant emphasis on bioeconomy, aiming to achieve a balanced integration of ecology, industry, and economy [6]. Another definition of this vision, by the European Union, is related to a purposeful adoption of technology towards sustainable, resilience, and fulfilling life of the industrial workers [7]. However, applying the term "Industry 5.0 ″ universally may not suit every context.

Then, the perspective of Society 5.0 that has similar based line, integrates more aspects of social dynamics such as ethics and enrich dimensions of the purposeful and fulfilling life. It asserts that through cyber-physical spaces, there exists the potential to achieve a balance between economic solutions for social issues, thereby fostering a life characterized by happiness and fulfilment [8,9]. Positive historical productivity and economic growth was measured in Germany and Japan after adopting the approaches and generate information communication technologies as part of the national strategy [8]. The merge between the industry and the normal life of the workers could imply that human body modification seems to be expressed in the future as cyborgs.

However, these strategies have not be able to management challenges (mentioned in Table 1) such as ethical considerations loom large by bioprocessors awareness, encompassing issues of privacy, data security, and the ethical implications of integrating advanced technologies like AI and cyber-physical systems into daily life. Socioeconomic acceptance presents another hurdle, with potential societal resistance stemming from concerns over job displacement and shifts in societal norms. Establishing robust regulatory frameworks that balance innovation with societal protection proves complex, requiring nuanced approaches to address legal gaps and ensure responsible technology deployment. Moreover, equipping the workforce with requisite skills and fostering digital literacy are pivotal for inclusive technological integration. Economic disparities may widen if technological benefits accrue unevenly across regions and demographics. Finally, in a deeper

Table 1
Policy limitations and challenges.

Category	Policy Strategy	Limitation	Challenges
Ethical Policies	Data Privacy and Security	Privacy Concerns	Despite efforts, ongoing concerns over data breaches and misuse.
	Equity and Inclusivity	Bias and Discrimination	Implementation gaps persist, hindering inclusive outcomes.
	Transparency and Accountability	Public Acceptance	Challenges in achieving full transparency and trustworthiness.
	Computing Awareness	Rights and Fair policies to bio upgrades	System hybridization with humans
Social Policies	Community Engagement	Public Acceptance	Difficulties in fostering genuine engagement and participation.
	Education and Digital Literacy	Digital Divide	Inequities in access and skills hinder digital empowerment.
	Workforce Development	Digital Divide, Public Acceptance	Gaps in skills and acceptance of new technological paradigms.
Technical Policies	Scalability and Interoperability Standards	Scalability and Interoperability	Standards variations and interoperability challenges persist.
	Infrastructure Investment	Scalability and Interoperability, Cybersecurity Risks	Insufficient investments may compromise system resilience.
	Innovation and Research Support	Scalability and Interoperability, Cybersecurity Risks	Limited breakthroughs in addressing complex cybersecurity issues.
External Factor	Pandemic Response	Public Health, Resilience	Impromptu responses may not be sustainable for future crises.
	Climate Change Mitigation	Environmental Impact, Sustainability	Insufficient integration of sustainability in technological advancements.

sense in adding a less dense space for living, cybersecurity emerges as a critical concern amid heightened digital connectivity, necessitating robust measures to safeguard against cyber threats.

Under both strategies, there is potential for technology to support biological enhancements as computational capabilities develop. This evolution may lead to societal changes, including the digitalization of human experiences through methodologies like digital twins and hybridization for bio upgrades. However, current cases of such advancements are insufficient, highlighting the need for further exploration and development in these fields. Nevertheless, what transformative steps are necessary to transition into a cyborg reality?

2.2. Digital twins and metaverse for urban management

Digital twin technology represents a contemporary methodology for replicating the dynamics of a physical environment in a digital format throughout all project phases. This approach provides a digital replica of physical experiences, enabling a more resource-efficient and cost-effective solution, by simulating real-world dynamics in a virtual space, similar to video game generation. Digital twins facilitate interaction, learning process, supply chain integration, and information sharing among various stakeholders regarding events yet to occur or replications of past experiences and physical environments.

Digital twin incorporates real-time modelling, simulation, autonomy, agent-based modelling, machine learning, prototyping, optimization, and big data analytics into a unified framework. This technology has been applied in fields such as smart cities, public health, and interplanetary studies, aiding in the development of novel software solutions for commerce, emergency services, real-time monitoring, and predictive maintenance [10]. Additionally, it enhances efficiency identification in human-robot collaborations, provides early warning signs of technical issues in medical systems like Magnetic Resonance Imaging and Computed Tomography scans, facilitates the creation of digital assets and simulate Metal smelting behaviour [11]. Furthermore, digital twins prevent emergent behaviours and establish a bijective information flow between physical and digital assets, thereby optimizing overall system performance and reliability [12–14].

Nevertheless, each application of digital twin reveals a group of interdisciplinary scientists recreating reality in another realm. This time-consuming data generation could be an asset for public domain to generate knowledge and understanding on how should be best to interact with certain situations.

Furthermore, the sale of 3D models on cloud platforms, the amalgamation of technological progress and architectural innovation underscores the industry's eagerness to embrace new horizons. Acquiring a 3D digital twin of a human body as well as a replica of their brain thought process could be the initiation of decentralized systems for human interactions [15]. However, the intricate relationship between technological innovation and industry-wide adaptation underscores the need for strategic alignment among professionals and stakeholders [16].

In a scientific way, the transformative potential of the construction industry extends beyond mere adaptation, with the advent of a digitally manifested, less dense reality. This pioneering concept envisions the integration of genetic information into the digital framework, fostering evolutionary progress and the creation of novel materials for sustainable and conscious-centric built environments. The promising role of biotechnology in reshaping these frontiers is evidenced by studies exploring biodegradable robots and eco-friendly robotics, enhancing the ecological applications within architectural contexts [17–20].

However, the humanity could take a path of merging with non-biological components as robots in a transhumanistic approach, regardless the robustness, complex, and supportiveness are alive entities against silicon-based technologies yet for just automating tasks. Despite the remarkable adaptability of human bodies to natural environments, it is imperative to consider the implications of transitioning consciousness into a cyborg state or integrating individuals into the ethereal realms of the metaverse. Humans with impediment of translation by health or economical reason could be a potential target to benefit from digital experiences.

Furthermore, beyond technological innovation, advancements in metaverse architecture have the potential to facilitate immersive interactions and dynamic engagements for human users. Much like the coexistence of microorganisms within the human body, the urban landscape becomes a canvas for diverse insights and experiences. From disaster management strategies to sensory perceptions of space and materials, the metaverse emerges as a realm for envisioning, sharing, and generating multifaceted urban insights [21].However, this paradigm shift necessitates a delicate balance between technological integration, regulatory and ethical considerations in urban development [22,23].

In this context, the development of automation tools and robotic systems plays a crucial role. This path emerges from the degree of embodiment of robotics in the organization. The embodiment process can be from bioengineering to disembodied intelligence according to the Robot Taxonomy Project by the Robot Identification Institute. The process is described by four main pilar: Humans, Cyborgs, Machanica and Program. In the first Humans are classified as workers as nowadays, then this kind of workers can be cloned and belong to a manufactured line of humans, mutations are a variable that during the cloning process may arise and finally transgenic humans are delivery on demand. The next stage is the cyborgs. This stage merge humans with robotics capability to surpass limitations of the humankind. It is achieved by endo-skeletal, prosthetics and exo-skeletal. After a fully integration of cyborg is carried out, the mechanica stage is came up with automata, humanoid, machinata and creaturoid. This stage is the recreation of flesh body reality into a silicon and titanium-based form. Ultimately, the evolution of this program stage correlates with the advancement of silicon and titanium-based forms that integrate fully developed computer systems, artificial intelligence, and disembodied intelligence as a central control mechanism. In modern society, automation is becoming pervasive across computing and machinery, incorporating smart devices along with quantum and unmanned systems such as biological quantum unmanned aerial systems and humanoid robots like Sophia from Saudi Arabia. In the following years, development on quantum technology will allow rapid results on experiments such as humans' waves pattern recognition for measuring subjective things as feelings [24]. This experiment is liaising sustainable integration and directly interaction of human's consciousness with external body elements in daily operations.

Considering recent global challenges such as the COVID-19 pandemic, industries like technology and manufacturing have demonstrated resilience through robotic automation, enabling remote work capabilities and enhancing productivity under social distancing measures. Conversely, sectors like construction have faced delays and innovation gaps, impacting national GDP and highlighting the need for digital transformation strategies [25]. The normal rates of the industry are 5–15 % of the overall national budget and, in developed nations, could be up to 50 %. Consequently, organizations have been adapting digital strategies within workflows, thus enhancing economic effects of the COVID-19 as the manufacturing have done with robots and intending with artificial intelligence. However, barriers persist that the current availability of silicon-plastic-metal-based systems could dismiss the impacts.

Looking ahead, as urban environments extend into the metaverse, new paradigms in urban planning and interaction emerge, accompanied by complex socio-technical challenges. The integration of human consciousness and AI avatars within the metaverse realm raises ethical queries regarding privacy, AI sentience, and the impact on human behaviours [26]. The metamorphosis of urban landscapes towards a digitized existence demands careful consideration of governance, regulations, and interoperability [22]. This intricate interplay between human experience, technological augmentation, and societal dynamics requires a holistic approach that transcends disciplinary boundaries.

As technological landscapes evolve, the construction industry stands at a crossroads of unprecedented possibilities. The envisioning of a Meta Smart Twin City intertwines biotechnology, metaverse integration, and architectural innovation, propelling the industry into uncharted territories. However, the transformative journey is not devoid of challenges, ranging from ethical dilemmas to socio-technical complexities as in Table 2. Navigating this trajectory necessitates a multidimensional approach driven by collaboration, interdisciplinary dialogue, and a conscious commitment to shaping a future that harmonizes technological advancement with human values.

3. Cognitive realities and technological interfaces: unveiling the nexus of digital twins, metaverse, and smart cities

Humans employ language to collaboratively construct a shared reality within the minds of their fellow humans. However, this constructed reality, shaped by the interactions among individuals, is constrained by the ethereal confines of their cognitive sphere, thereby exerting influences in the realm of cyberspace. Within this framework, distinct groups of humans, akin to tribes, develop unique symbols, sets of memories for interpretation, and synaptic connections that cause variations in the form, content, significance, and intention of ideas across individuals. Consequently, the languages employed by organic entities possess a complexity that potentially surpasses that of silicon-based digital languages.

The conversion of human languages and their corresponding interpretations into binary signals for servers, machines, or platforms establishes a fundamental means of communicating this reality uniformly among diverse entities. In this process, human interactions, aimed at replicating their organic milieu, are manifested, particularly when engaged with another human. Binary codes encapsulate the representation of structures, infrastructures, and urban landscapes, encompassing their geometry and fundamental attributes like temperature and texture.

However, the digital "genetic makeup" underpinning this constructed reality remains bounded by the grasp of human capabilities and the dynamics of the physical world. As efforts towards simulating various life forms intensify within less dense digital environments, this endeavour necessitates substantial assistance from species sharing an analogous biological foundation, such as autonomous systems [27,28].

The designation of physical cities, or clusters of inhabitants within tangible edifices made of wood, concrete, or steel, as "smart" arises from the integration of informational components from silicon-based entities into the human habitat. This assimilation of elements or "chromosomes" from less dense digital realities into the corporeal realm gives shape to this concept. Consequently, the realization of this concept occurs when humans on a larger scale harness digital and silicon-based entities or information-processing mechanisms for their well-being [29].

The translation of the intricate reality, whether through cloud uploads or human-orchestrated means, involves not only human agency but also silicon-based entities or self-governing systems like robots and advanced printers. Despite the vulnerabilities of silicon-based entities to solar perturbations, the symbiotic fusion of genetics and technology appears poised to surmount challenges in constructing a multifaceted universe of existence [30,31].

Transitioning into the metaverse, humans engage with reality interfaces within a digital domain populated by artificial, silicon-based entities. This virtual realm is conjured into being through specific interactions within the physical world. Smart cities within this binary landscape, furnished by spiritual entities, facilitate the fusion of the metaverse with the animate entities of digital twins. This nexus encapsulates the structures or experiences within this metaverse. However, the digital twin only replicates the spatial or objective aspects, excluding the dynamic interactions of humans within. As the metaverse is primarily geared towards human engagement in binary code experiences, it refrains from encompassing representations of species beyond humans

Table 2
Ethical dilemmas.

Dilemma	Description	Comparable Variable	Possible Solution
Consciousness and sentience	If a bioprocessor achieves a level of complexity that mimics a human brain, would it be conscious or sentient? This raises ethical questions about its treatment and rights.	Animal sentience	Develop clear criteria for determining sentience in biological and artificial systems. Establish ethical guidelines for the treatment of sentient beings, regardless of their origin.
Animal welfare	If bioprocessors involve using animal brains or brain organoids, concerns arise about animal welfare. Would the extraction or manipulation of these biological components cause undue suffering?	Animal testing in research	Develop alternative methods that do not rely on animal brains. If animal-derived components are necessary, implement strict ethical guidelines to minimize suffering.
Human enhancement	Bioprocessors could potentially be used to enhance human cognition. This could create an uneven playing field, with those who can afford bioprocessor implants gaining an advantage. Would this exacerbate social inequality? What would it mean to be human if our cognitive abilities could be augmented by technology?	Performance-enhancing drugs in sports	Regulate bioprocessor use to prevent excessive inequality. Ensure equitable access to this technology or find alternative methods for cognitive enhancement that are more widely available.
Control and ownership	Who would own and control bioprocessors? Would corporations or governments own them? This raises concerns about the potential for misuse and the commoditization of consciousness.	Ownership of artificial intelligence	Develop international regulations on the development and ownership of bioprocessors. Ensure transparency and accountability in the research and development process.
The nature of intelligence	Bioprocessors challenge our traditional definitions of intelligence. If a machine can achieve human-like intelligence through biological means, does that change what it means to be intelligent?	The definition of life	Re-evaluate our understanding of intelligence to encompass both biological and artificial forms. Focus on the capabilities of intelligence rather than its origin.
The definition of life	What does it mean for something to be alive if a machine can exhibit characteristics we associate with life, such as learning and adaptation? Bioprocessors blur the lines between machine and organism.	The definition of consciousness	Engage in open discussions about the definition of life considering new technologies. Consider the importance of biological processes vs. functional

(continued on next page)

Table 2 (*continued*)

Dilemma	Description	Comparable Variable	Possible Solution
			capabilities when defining life.
Free will and determinism	If bioprocessors are used to create artificial intelligence (AI), would this AI have free will or be simply a complex deterministic system? This raises questions about responsibility for the actions of such AI.	Deterministic vs. probabilistic AI	Develop AI with the capacity for independent decision-making and adaptation within ethical boundaries. Clearly define the lines of responsibility between developers, users, and AI for its actions, implementing robust safety protocols. Explore the concept of "explainable AI" to understand the reasoning behind AI decisions.
The purpose of technology	Bioprocessors raise questions about the purpose of technology in human society. Should technology be used to augment human capabilities or redefine what it means to be human?	The role of technology in society	Foster public discourse about the desired role of technology in human lives, focusing on human-centred design principles. Ensure that bioprocessors are developed and used in a way that complements and enhances human existence, promoting collaboration and innovation. Encourage responsible development that prioritizes human values and safeguards against negative societal impacts.
Existential risk	Some experts worry that advanced AI could pose an existential threat to humanity. Bioprocessors, if capable of exceeding human intelligence, could potentially fall into this category.	The control of advanced AI	Implement safeguards to prevent bioprocessors from surpassing human control. Develop fail-safe mechanisms and clear protocols for the development and deployment of such advanced AI. Promote international cooperation and collaboration on AI safety research. Create independent oversight bodies to monitor the development and deployment of advanced AI to mitigate potential risks.

or the comprehensive reconstruction of physical environments [32].

Yet, as humans design the metaverse, autonomous physical systems hold the potential to enable the recreation of binary experiences, grounded in the digital twins of our dense reality. In essence, digital twins manifest as the animated constituents of the digital expanse, wherein humans engage in both cyber and tangible interactions.

In summation, the representation of binary code within a digital milieu encapsulates the concept of a digital twin. The metaverse serves as the locus of these interactions, while the notion of the smart city envisions a reality fostering enhanced health, productivity, energy efficiency, sustainability, built surroundings, and overall urban well-being. Following these delineations, the subsequent section expounds upon applications and points of convergence within the realm of construction.

4. Applications and convergent points of a digital twin concept in construction

The practical applications of these concepts hinge upon their fundamental purposes. The strategic vision underpinning smart cities aims to enhance physical environments through the infusion of digital and silicon elements. A "digital twin" stands as a representation of both the tangible and binary realms, while metaverses serve as conduits for assimilating individuals into alternate realities transcending the physical realm. Concurrently, autonomous systems are intended for diverse functions, including human transportation, digital financial transactions, as well as the digital surveillance of urban functions and interactions encompassing traffic, healthcare, and energy management [33,34].

Hence, the construction and prognosis of these urban landscapes are initially executed within a digital domain, resulting in the creation of a binary "genetic" counterpart that offers insights into its hypothetical behaviours under ideal conditions. Abundant data is culled from the tangible realm, subsequently informing refinements to the binary parameters and principles of the simulated environment. In contrast, in the context of the metaverse, facets related to financial transactions, engagement dynamics, and emotional experiences are predominantly rooted within the human domain, rather than being intrinsic to the virtual space [4,35]. The metaverse possesses the capacity to absorb user feedback, thereby enabling a cycle of iterative enhancement.

This convergence of virtual and tangible experiences further permits the monetization of architectural encounters within the framework of the digital twin, interconnected with a metaverse where users exercise the option to invest in and/or materialize physical assets inside a blockchain system under zero-knowledge proof systems. From a governmental standpoint, the simulation of infrastructures within the metaverse facilitates testing and training for maintenance procedures. Prospective infrastructural damages can be identified and preemptively addressed through this approach [36]. On a broader spectrum, municipal authorities might contemplate devising bespoke metaverses for transactional systems centred around experiences unique to online urban environments. This strategic utilization of cyberspace data aids in determining optimal business placements within the physical realm, a strategy aligned with the overarching aim of achieving net-zero carbon emissions by the incentive of circular economy, renewable energy integration and green building practices.

Nevertheless, a myriad of avenues beckon for exploration, including the realms of tourism and urban development. The commercial ramifications encompass the trade of virtual "real estate" to gamers via 3D models, alongside the potential to import avatars from diverse platforms. Such endeavours have the potential to foster the growth of distinct metaverse communities within each nation. For instance, gaining access to the metaverse associated with a particular city grant individuals exposure to tangible experiences, encompassing scenic sunsets, museum visits, and networking opportunities. Additionally, this platform facilitates interaction with AI-driven mentor avatars and

globally recognized authorities in various fields, for a stipulated fee. This paradigm establishes a sustainable foundation for both entertainment and educational pursuits, fostering real-time engagement.

5. Developing interactions of a metaverse in the construction industry

The convergence of digital environment design with human interaction, entailing transactions, digital twins, and metaverse engagement, underscores a nuanced exploration. Should governmentally bodies and policymakers play a role in metaverse design or should a meta-city platform incorporate policy aspects like taxation and experiential regulations? the paradigm of a smart meta twin city manifests relevance. As it matures, delineating the optimal trajectory for this concept's realization necessitates strategic considerations. Contemplating the requisite proficiencies and taxable constituents is pivotal, as is discerning the interface of professionals with these multifaceted dimensions.

The efficacy of the development trajectory is fundamentally contingent on the precision of construction dynamics, which in turn wield authority over developmental parameters and cost implications. A council metaverse's accessibility from diverse platforms, coupled with the technical prerequisites underpinning experiential production, stand as pivotal factors influencing the calculus surrounding taxation strategies for products, services, or experiences. Furthermore, the developmental phase of the meta smart twin city offers an avenue for the integration of digital add-ons. To elucidate, the innovation of novel digital products corresponds to the burgeoning demand within the digital metaverse business landscape. Consequently, diversifying the array of accessible products and services aligns with augmenting the experiential fabric within the metaverse domain.

In the context of taxation strategies, their profound impact on metaverse development becomes evident, shaping the metaverse's structure, growth trajectory, and economic sustainability. Given the intricate digital milieu characterized by transactions, interactions, and the virtual asset trade, the nuanced considerations of tax implications assume significance. Notable ways in which tax strategies exert influence on metaverse development are outlined as follows.

- Incentivizing Development: Governments can leverage tax incentives to encourage investments in metaverse-related initiatives. By extending tax breaks, credits, or deductions to entities engaged in metaverse development, innovation and expansion in this realm can be spurred.
- Determining Taxation Points: The identification of tax imposition points within the metaverse ecosystem is pivotal. Transactions encompassing the exchange of virtual assets, goods, or cryptocurrencies within the metaverse may trigger tax obligations. Clear guidelines for these taxation junctures are essential for compliance and revenue generation.
- Virtual Property and Transactions: The metaverse hosts a realm of virtual property, land, and assets subject to buying, selling, and trading. Tax policies must address the taxation of such transactions, determining whether capital gains taxes, value-added taxes, or other levies are applicable.
- Digital Goods and Services Taxation: Virtual goods and services within the metaverse, such as digital art and experiences, may be subject to consumption or sales taxes. The intricate task of determining the applicability and calculation of taxes on intangible digital offerings requires careful consideration.
- Cross-Border Transactions: The global nature of the metaverse necessitates addressing cross-border transactions. Considerations such as tax treaties and international tax regulations come into play when virtual assets and services traverse borders.
- User Income and Profits: Individuals generating income within the metaverse, through virtual commerce or content creation, may face income tax. The characterization of such income and the mechanisms for reporting and remitting taxes on virtual earnings necessitate careful delineation.
- Regulatory Compliance: Tax strategies must harmonize with regulatory frameworks governing the metaverse. Balancing innovation and compliance with existing tax laws is crucial.
- Tax Efficiency for Businesses: Businesses in the metaverse may seek tax-efficient structures for operational optimization. This might entail setting up in favourable tax jurisdictions or employing tax planning techniques to minimize tax liabilities.
- User Engagement and Incentives: Tax strategies can influence user engagement. Incentives or rewards offered to metaverse users may have tax implications, necessitating the design of incentives with a comprehensive grasp of tax consequences.
- Encouraging Responsible Growth: Tax policies can be crafted to foster responsible metaverse growth, curbing speculative trading and preventing illicit use of virtual assets.

In conclusion, the integration of digital and human dimensions in the metaverse, coupled with the implications of tax strategies, engenders a multifaceted terrain that necessitates meticulous attention to foster sustainable development.

6. Stakeholders interaction of digital twins and metaverse

As we witness the ongoing digital transformation of our physical environment, the human influence extends boundlessly into the realm of digital dimensions. This influence profoundly shapes the educational content pertinent to construction practitioners, bearing in mind the kind of experiences individuals might wish to encounter within either the tangible or virtual domains [37]. Within the industry, diverse professionals may find themselves necessitating shifts in their responsibilities, albeit not in their nomenclature. Those hailing from the gaming sector, for instance, harbour a desire to craft experiences transposable from the virtual realm into the tangible world. To illustrate, those experts who intricately design the narratives of video games could artfully apply analogous methodologies to the conception of video games that amplify the user experience within physical edifices and urban landscapes.

Subsequently, architects, who shepherd these creations through the sales process, can meticulously evaluate whether these experiences find superior manifestation within the palpable or digital expanse. Moreover, assuming the role of a cognitive undertaking, managers must possess the capability to furnish clients with specific experiential paradigms. This entails determining the optimal hours for meticulous scrutiny, aligning with the temporal investment essential for exhaustive programming, as well as gauging the quantifiable facets of this endeavour—up to a certain point. At this stage, the potential for automation, supported by well-structured contracts, enables the self-coordination of both virtual and physical interactions [38].

Nonetheless, clients possessing a less informed perspective might encounter pronounced challenges when grappling with the intricacies of business proceedings that intersect with the metaverse and smart cities, mediated through the conduit of the digital twin. Nevertheless, resources are poised to become available, imparting knowledge to clients in their comprehension of the blockchain system and the constituents underpinning investment strategies within these modalities of enterprise. The transition towards an archival digital rendition of corporeal reality mandates a judicious equilibrium, thereby steering human cognition towards the concurrent contemplation of both experiential dimensions. It is pivotal, however, for these seasoned practitioners to be buttressed by technologies that capture reality with fidelity, thereby preserving the veracity of the physical actuality.

7. Reality-capture technologies and decentralized systems

7.1. Definition of a reality-capture technology

Reality-capture technologies encompass the acquisition of data emanating from either the corporeal or biological domains, subsequently transmuting these data into a binary lexicon. This term is centred upon mechanisms and automatons that furnish the digital realm with discernible content. Given that these sensors are conceived and erected by human agency, the emulation of sensory apparatuses, both intrinsic and surpassing human biological limitations, serves to foster an augmented cognizance pertaining to the tangible reality. Human apprehension of the physical realm is contingent upon the faculties of their quintessential five senses.

Upon immersion within the metaverse, the very notion of reality undergoes a paradigmatic shift, being projected from an alternate virtual realm and experienced through the prism of two out of the quintet of human senses. The duality of these senses proves sufficient to engender physiological impulses within our corporeal framework and incite alterations within the user's belief systems. The encounters unfurled within the metaverse imprint themselves onto our genetic code, seamlessly integrating with the compendium of human DNA. Emotions transmute into corporeal manifestations, thereby amplifying our perceptual horizons and cascading across successive generations as an indelible repository of experiential wisdom.

7.2. Types of reality-capture technologies

A diverse spectrum of reality-capture technologies exists, tailored to the extent of data collection required and the complexity of environmental reconstruction. Often referred to as unmanned systems, each of these technologies employs distinct methods for processing information. Upon integration with the Internet of Things (IoT), these systems execute directives governing behaviour and offer remedies for urban challenges. In specific contexts, such mechanisms are harnessed for the orchestration of diverse cultural enclaves and locales, serving as a conduit for transmitting methodological information to facilitate physical interactions within hazardous domains.

Fig. 1 presents the different types of commercial unmanned systems for reality capture purpose.

Certain iterations within the literature are conceived to operate autonomously up to a certain threshold, albeit the predicament of energy remains inadequately tackled. These technologies hold the potential to address urban maintenance and transformational tasks by operating in tandem with IoT through binary digital instructions. Consequently, the emulation of non-human entities executing physical interactions can be simulated to furnish transactional encounters within the metaverse. Among the technologies facilitating this paradigm, unmanned aerial systems or drones emerge as prominent contenders. Their sensors adeptly amass data and, alongside other tools, process information essential for digital reconstruction or provision of virtual reality-based frameworks for experiential design. Subsequent to data acquisition and processing, the digital rendition of cities across temporal and

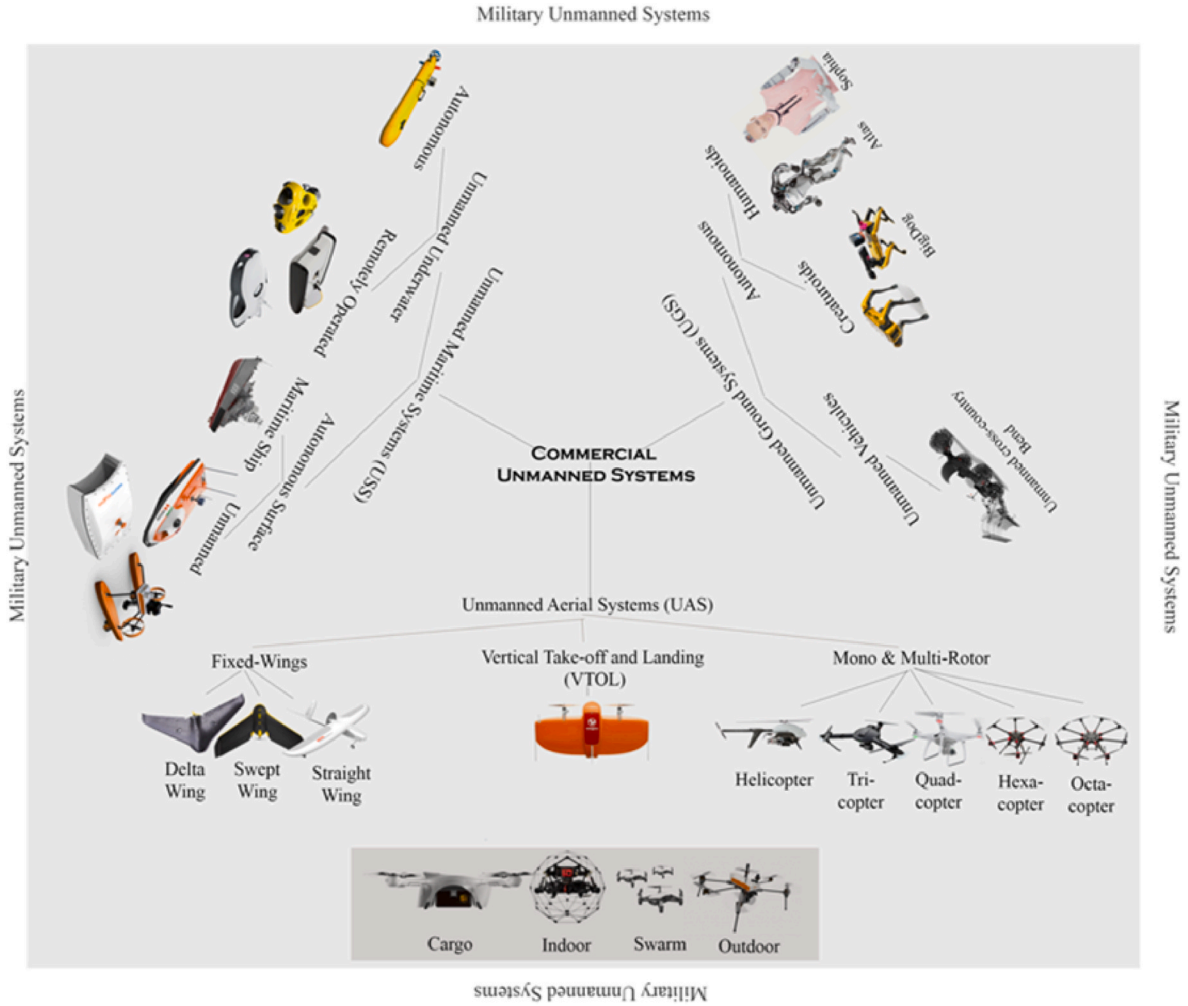

Fig. 1. Unmanned Systems for reality capture.

spatial dimensions yields informative insights into their statuses.

However, considering the inherent limitations in human data processing speed, artificial intelligence algorithms can be extensively trained to discern infrastructural issues by comparing the initial digital replication with subsequent iterations. Consequently, these dynamics possess the potential to reshape digital experiences, as each twin introduces novel elements that engender modifications to the metaverse's preferred Euclidean geometry. Illustrative instances wherein such frameworks offer substantial contributions encompass flood management simulations, accident analysis, cyber domain discussions concerning environmental matters, and more.

7.3. Decentralized systems

Three distinct frameworks govern the operations of blockchain networks, each delineating a unique approach: centralized, decentralized, and distributed. These frameworks facilitate diverse modes of information interchange and stakeholder governance. In the context of autonomous systems, the decentralization of data interaction assumes paramount significance. This design choice enables the digital twin to be imbued with real-time updates, thereby affording other agents the privilege of accessing the primary wellspring of information. Such access becomes indispensable for contributing inputs aimed at refining the system, particularly in cases where discrepancies in the precision of geometries and information exchange arise, as encountered in Neural Radiance Fields or photogrammetry methodologies.

Fig. 2 is presenting how different metaverses would be linked and interact between different blockchain frameworks.

Furthermore, characterising the frameworks, in the centralized systems the control and decision-making are concentrated in a single central entity. Efficient coordination but single point of failure. On the decentralized systems the control is distributed across multiple nodes without a single point of control. Enhanced security and transparency compared to centralization. Finally, in distributed systems, the data, control, and computation are distributed across multiple nodes, often geographically dispersed. Prioritizes fault tolerance and scalability.

The choice between these frameworks depends on factors such as the nature of the application, security requirements, scalability needs, and the level of trust desired within the system. Moreover, in the context of the future roadmap for Meta Smart Twin Cities, the choice of framework—centralized, decentralized, or distributed—will significantly shape the architecture, functionality, and governance of these cities' technological infrastructure. The approach chosen will have profound implications for how data is managed, exchanged, and utilized within these smart urban environments. Ultimately, the choice of framework will depend on factors such as the city's goals, the level of stakeholder involvement desired, the complexity of the urban environment, data security concerns, and the technological capabilities available. For example, by decentralization, distributing responsibilities, resources, and redundancies, such systems are better equipped to withstand disruptions, maintain functionality, and recover swiftly from failures. As a result, distributed frameworks are well-suited for applications requiring high availability, fault tolerance, and adaptability, making them particularly valuable in the context of smart cities, critical infrastructure, and complex interconnected systems. However, for rapid decisions decentralization might not be fully suitable during a disaster. In many cases, a hybrid approach might emerge, combining elements of centralized, decentralized, and distributed frameworks to create a balanced and adaptable system for Meta Smart Twin Cities.

8. Framework and road map for meta smart twin cities and implications

8.1. Novel user experience framework for construction products

The explorations into the metaverse have far-reaching implications

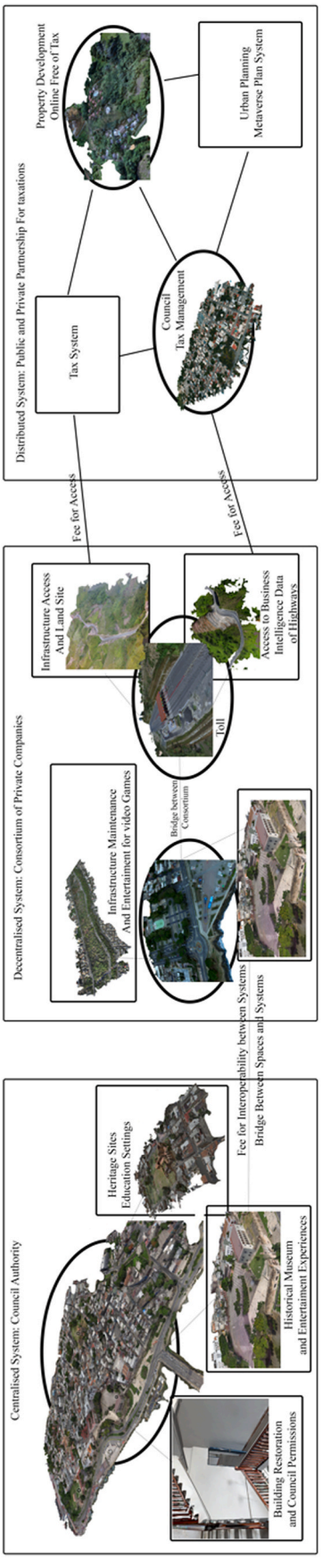

Fig. 2. Decentralized system Graph.

for diverse domains, including governance, climate change mitigation, tourism, resource management, and geographic information systems (GIS). However, the nascent nature of the metaverse raises concerns that necessitate regulatory oversight. These concerns encompass the potential psychological ramifications of predominantly digital existences, alongside issues relating to data privacy, control, and the profiling of avatars through social media platforms. Notably, while the scientific community actively scrutinizes the potential behavioural dimensions of the metaverse, critical questions loom. For instance, the articulation of scenarios elucidating the priorities of future collaborative agendas assumes significance for all stakeholders. Considering this, the inquiry into how cities should evolve to facilitate metaverse interactions gains prominence? Will cities primarily cater to tourism and commerce, or will they encompass experiences transcending the physical realm, such as virtual roller coasters and animated spaces?

The proposition of metaverse-driven urban centres carries the potential to address tasks that diverge from sustainable practices, while recalibrating the allocation of human energies through the decentralization of both physical (construction - related) and digital (transactional) occupations in infrastructural development. In an ideal scenario, these elements would engender progress in multiple realms: the refinement of tools for digital interaction and manifestation, particularly within unmanned systems; the diversification of skills among professionals to encompass roles as architects of digital experiences within metacities; and the scalability of these concepts across varying stakeholders and surfaces, including extraterrestrial domains such as Mars or the Moon [39,40]. Simulating the behaviour of cities within space conditions becomes a prerequisite for populating other planets, ensuring the sustainability of such ambitious construction projects. The interplay and extension of these concepts, along with the components constituting each, are visually represented in Fig. 3. This depiction underscores the interconnected nature of these concepts and their predilection for manifesting across distinct dimensions of reality.

In Fig. 3 is described the three main strategies. Smart cities are related to government, digital twin to manufacturing within construction, and the metaverse related to the user. Each concept is fed with data gathered and constructed by humans directly or through other devices. The more digital is the concept, the more translation methods and tools will be required to supply functionality to the concept. For example: as a smart city strategy, multiple blockchain of online stores, in the metaverse, can digitally represent the dynamics of the physical store. In some cases, the store can have features online that in physical version should be avoided for health and safety and vice versa. Nevertheless, incentivizing mobility (digital or physical) for certain periods will determine how cities may be built or restore and what kinds of construction products are suitable for contractors and final users.

8.2. Future road map of meta smart twin cities

The trajectory of these methodologies holds a significant bearing on diverse domains, including training, entertainment, and the decentralization of systems pertinent to the constructed environment. The emergence of Meta Smart Twin Cities represents a paradigm characterized by digital replicas that operate cohesively within the physical realm, coexisting harmoniously with components of the virtual landscape. This symbiotic relationship between physical and virtual dimensions engenders a dynamic interplay, enabling transparent interactions that redefine urban experiences.

Integral to this paradigm is the utilization of unmanned systems to underpin various urban initiatives, such as construction projects and infrastructural enhancements. These systems, often characterized by autonomy and technological sophistication, play a pivotal role in facilitating the translation of tangible urban structures into their digital counterparts. This initial phase entails meticulous data capture and digitization, effectively culminating in a cohesive virtual representation of the urban landscape. Subsequently, the integration of these virtual constructs with blockchain systems introduces a layer of transparency, security, and traceability to transactions within the virtual realm.

Further augmenting this evolutionary trajectory are platforms that cater to the refinement and enrichment of virtual reality experiences. These platforms facilitate dynamic engagements and interactions within the digital domain, mirroring and sometimes even surpassing corresponding experiences in the physical world. The seamless integration of physical and virtual facets nurtures a novel dimension of urban interaction, engendering a landscape characterized by fluid transitions and interwoven narratives.

However, this visionary pursuit is accompanied by multifaceted challenges that warrant consideration. The elucidation of chromosomal formations, often relegated to the realm of genetics, introduces a contemplative layer to the digital space. As a potential determinant of cognitive paradigms, these findings could potentially reshape the very nature of human interaction within the digital realm.

Monetization strategies for this emergent virtual sphere hinge upon the concept of non-fungible tokens (NFTs), which serve as unique digital artifacts tethered to specific experiences or components within the virtual environment. By leveraging blockchain technology, these tokens confer ownership and provenance to virtual entities, facilitating the creation of digital assets with tangible value [41,42]. The preservation

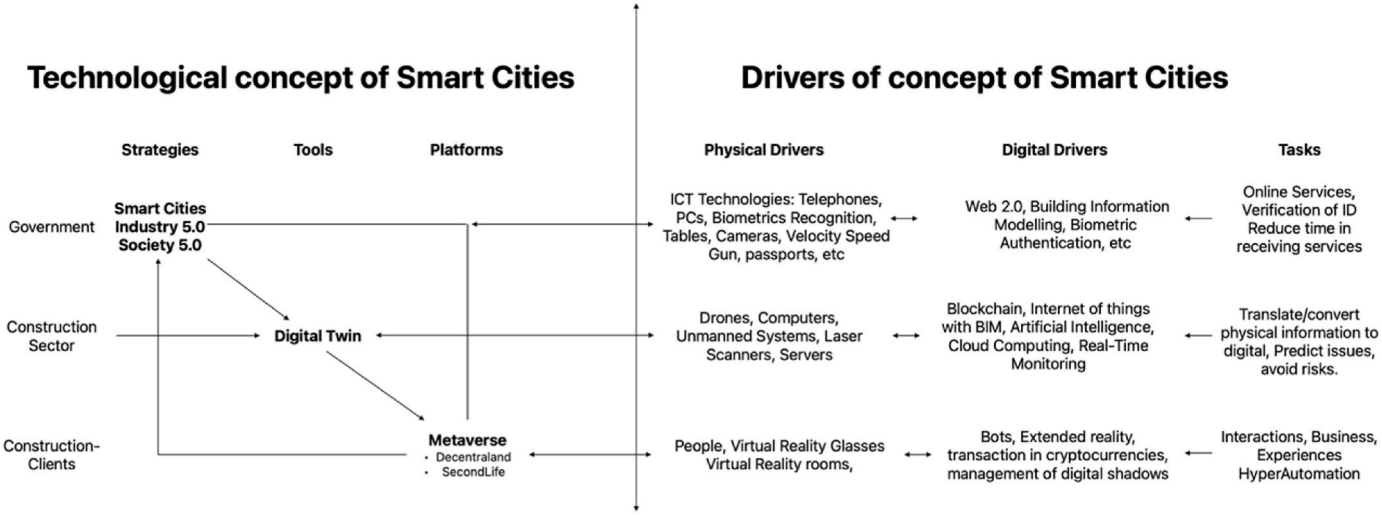

Fig. 3. Intersections and key elements of smart cities, digital twin and Metaverse.

of select experiences or digital imprints as legacies for posterity encapsulates a forward-looking approach, underscoring the desire to capture and immortalize the evolving landscape of urban engagement.

However, the transformative potential of this paradigm faces formidable social barriers that necessitate careful navigation. Acceptance and privacy concerns loom large, as individuals grapple with the implications of their interactions within an intricately connected digital milieu. Overcoming these hurdles requires thoughtful design and robust regulatory frameworks that safeguard user rights and instil trust in the virtual landscape.

Profitability, often harnessed as a driving force, is poised to be a principal catalyst in the expansion of this nascent domain. The demonstrable economic viability of use cases within the Meta Smart Twin Cities framework holds the potential to garner stakeholder interest, investment, and commitment, thereby underpinning its evolution and growth.

In light of the aforementioned considerations, it is prudent to advocate for further empirical endeavours aimed at concretizing the conceptual underpinnings of this paradigm. The development and testing of a minimal viable product (MVP) assume particular significance, affording an avenue for empirical validation and assessment. Such endeavours stand poised to furnish invaluable insights into the fidelity, responsiveness, and applicability of this vision to real-world business cases as presented in Fig. 4.

As the horizon of urban engagement continues to evolve, propelled by technological ingenuity and visionary endeavours, the landscape of Meta Smart Twin Cities represents a profound synthesis of the physical and the virtual. This synthesis, while laden with challenges, emerges as a promising pathway toward redefining how urban environments are experienced, understood, and co-created.

Fig. 4 shows the variable interactions to make urban environments aligned with the meta Smart Twin City.

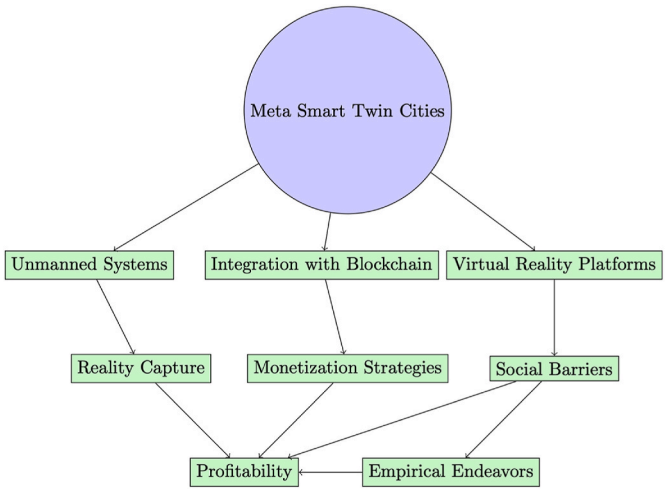

Fig. 4. Framework for integrating Meta Smart Twin Cities into Physical world.

9. Conclusion

The objective of this study was to explore the existing challenges, identify gaps in current literature, and propose strategies to enhance the resilience and adaptability of urban systems. The paper explored international strategies or visions and delineated challenges stemming from ethical, social, technological, and external factors influencing current actions. Furthermore, it was explored the ways digital twins, smart urban environments, blockchain technology, and other reality capture datasets contribute to the vision of digital and physical construction domains. Additionally, it was examined the interaction and convergence of new spatial constructs, highlight the critical role of data acquisition technologies, and present a comprehensive framework for user experience and the future of Meta Smart Twin Cities.

It became apparent that bioprocessors enhancing human capabilities position and potentially could influence the interactions within the metaverse, the less dense reality space is seeming as a potential platform for commerce, particularly advantageous during pandemics and for promoting inclusivity. However, ensuring a cohesive framework across diverse governmental jurisdictions is essential to achieve resilient outcomes, such as overcoming language barriers in education and facilitating mobility for marginalized.

The digital twin platform emerges as pivotal for enhancing the metaverse with high fidelity, augmented by cyber and physical robots such as unmanned systems for external tasks and automated digital operations. This evolution is expected to foster new career paths centred on understanding fundamental human values like ownership, early adoption, and uniqueness, facilitated by technologies such as the Internet of Things and blockchain within metaverse contexts.

Furthermore, implementing taxes on specific virtual experiences across different metaverse frontiers and potentially incentivizing the trade of digital assets could sustain commercial practices within less densely populated virtual environments. Individuals are likely to engage in physical trials of experiences before committing significant investments, shaping adoption patterns and the sustainability of virtual environments. Additionally, to be able to absorb wisdom from a virtual repository of experiences applicable for their own existential activities.

In conclusion, cities are actively developing metaverses, starting with low fidelity models that digital twin methodologies promise to enhance. Users will access unique experiences through a unified framework across multiple metaverses, supported by advanced robots and artificial intelligence. Ethical considerations, notably those surrounding transhumanism, underscore the imperative for humans to maintain their biological form to sustain life on Earth amidst developments in digital asset ethics within decentralized systems operated by unmanned and bot systems. Future research should delve deeper into these ethical axioms in the context of digital assets and decentralized systems.

Declaration of generative AI and AI-assisted technologies in the Writing process'

During the preparation of this work the author(s) used **CHATGPT 3.5 in order to improve readability of the article**. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

CRediT authorship contribution statement

Hamlet Reynoso Vanderhorst: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation. **David Heesom:** Writing – review & editing, Supervision, Resources, Conceptualization. **Komali Yenneti:** Writing – review & editing, Conceptualization.

Declarations of competing interest

None.

Data availability

No data was used for the research described in the article.

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