

QUANTUM URBANISM AND THE NFT NEXUS: REDEFINING VIRTUAL LAND VALUE IN DECENTRALIZED CITIES

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The intersection of quantum urbanism and non-fungible tokens (NFTs) offers a new paradigm for remapping urban futures, wherein digital and physical realms merge into dynamic, decentralized ecosystems. This article examines how quantum computing, by applying principles such as superposition and probabilistic optimization, can simulate extremely intricate urban systems, from energy networks to traffic patterns, with unprecedented efficiency. Meanwhile, NFTs are transforming the notion of virtual land ownership, allowing decentralized control and hybrid economies that bypass geographical constraints. By integrating these domains, cities can become vibrant spaces where quantum algorithms optimize virtual land value, and NFT-based platforms democratize urban development. However, this transformation poses fundamental challenges: the energy consumption of quantum-blockchain infrastructures risks compromising sustainability goals, while algorithmic opacity and digital divides risk reproducing historical inequalities in virtual realms. Ethical governance policy and principles must concentrate on renewable energy integration, algorithmic transparency, and fair access to prevent exploitation. Drawing from emergent metaverse economy trials and quantum urban simulations, the paper argues that such a nexus would be capable of driving Sustainable Development Goals (SDGs), namely SDG 9 (innovation), SDG 11 (sustainable cities), and SDG 17 (partnerships) if they are premised on participatory design and cross-sectoral collaboration.

Key words: quantum urbanism, NFT, virtual, land, decentralized cities.

INTRODUCTION

Urban planning's history has long been inextricably linked to the material, physical world, where infrastructure, zoning laws, and socio-economic pressures shape cities in the traditional sense. The 21st century has heralded a paradigm shift, however, driven by the rapid digitization of human existence and the rise of decentralized technologies. This has dissolved the boundary between the physical and virtual worlds, creating unparalleled opportunities and dilemmas for the rethinking of urbanism. At the confluence of this revolution are two innovative ideas: quantum urbanism, which uses quantum computing to streamline intricate urban systems, and non-fungible tokens (NFTs) (unique

digital certificates of ownership stored on a blockchain), which are transforming ownership and value creation in virtual worlds. In combination, these technologies disrupt traditional ideas of land use, governance, and economic fairness, providing a template for cities that transcend the limitations of physical geography.

Alvarez León and Rosen (2024) discuss the evolving understanding of land in line with virtual worlds such as the Metaverse, pointing out that virtual land is now a critical element in contemporary economies and social orders. The emergence of virtual worlds from blockchain metaverses like Decentraland to AI-emulated cityscapes has made "virtual land" a scarce, exchangeable commodity. Non-fungible tokens (NFTs), as digital certificates of ownership that are one-of-a-kind, have opened up a speculative but revolutionary market for such assets, allowing individuals and institutions to monetize creativity, governance rights,

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and even algorithmic decision-making in decentralized urban settings. This is reflected in contemporary discussions on the potential of decentralized digital assets to enhance new governance frameworks in urban planning (Alvarez León and Rosen, 2024).

Meanwhile, quantum urbanism promotes a revolutionary rethinking of urban planning through the use of quantum algorithms that can efficiently model hyper-complex systems such as energy networks and traffic flows, displaying an unparalleled degree of efficiency (Marchesin *et al.*, 2023). Such applications greatly enhance the capacity of urban planners to address complex urban issues and enhance the allocation of resources, underscoring the urgency for creative solutions in rapidly evolving urban settings (Giraldo-Quintero *et al.*, 2022). Current discourse around digital urbanism has a tendency to separate technological innovation from environmental management or socio-political equity. This work bridges the gap by proposing an interdisciplinary framework that combines the computational power of quantum urbanism with NFT-driven economic models to enable inclusive, sustainable, and resilient cities. Through case studies of nascent metaverse economies and quantum computing initiatives in urban planning, we contend that the intersection of these domains can democratize access to urban development, speed up achievement of the Sustainable Development Goals (SDGs), especially SDG 9 (Industry, Innovation), SDG 11 (Sustainable Cities), and SDG 17 (Partnerships), and reinvent wealth creation in a post-physical economy.

Nevertheless, this perspective necessitates immediate examination of the deficiencies in governance, energy usage, and disparities in digital access, in order to prevent the reproduction of past injustices in novel, algorithmically influenced manifestations. By critically analyzing these conflicts, this viewpoint seeks to stimulate an international conversation about reconciling technological aspirations with the fair and ecological necessities of future urban environments.

The research design for this study is classified as exploratory and integrative. Rather, the research will integrate understandings gleaned from a critical review of emergent literature at the nexus of Quantum Computing, Urban Studies, and Blockchain Economics. A cursory bibliometric survey of Scopus and Web of Science databases for the last decade reveals a rapidly growing but still niche body of literature, with sharp increases in publications on ‘smart cities’ and ‘blockchain’, and nascent but rising interest in ‘quantum computing’ applications for urban systems. The research is structured by way of conceptual triangulation, leveraging peer-reviewed scholarly literature, case studies of emergent economies within the Metaverse (Decentraland) and Quantum Computing pilot projects focused on urban planning. The research design and intentions do not seek to test a particular hypothesis but instead to develop a cohesive framework for multiple disciplines and to discern emergent opportunities and challenges for future urban development.

QUANTUM URBANISM: PRINCIPLES AND APPLICATIONS

Quantum urbanism is a radical break with conventional urban planning models, incorporating principles of quantum computing superposition, entanglement, and probabilistic optimization to envision and organize cities as adaptive, dynamic systems. Departing from classical models based on linear frameworks, quantum urbanism acknowledges and embraces uncertainty and complexity and views urban space as web-like networks of energy, information, and human activity. Quantum computing has the ability to simulate scenarios that are computationally expensive for classical systems, allowing, for example, the optimization of energy usage across a city in real time with changing demand or the prediction of traffic flows based on numerous interconnected variables. Quantum annealing has been proposed as a method of optimizing land-use priority blending housing density, parks, and commercial zones by testing numerous permutations more efficiently than classical models (Krantz *et al.*, 2019; Hassija *et al.*, 2020). Quantum urbanism applications extend beyond efficiency; they revolutionize the way cities learn and evolve. Urban infrastructure might autonomously respond to crises, such as climate disasters or pandemics, through quantum machine learning. For example, a self-reconfiguring power grid in the face of a heatwave in a matter of milliseconds can redistribute energy to impacted neighborhoods and remain stable; or a public transportation system can anticipate alterations in commuter patterns amidst a flood based on weather sensor information, social media, and IoT devices. These systems should not be viewed as static infrastructures but as dynamic ecosystems that reflect the probabilistic nature of quantum states (Helbing *et al.*, 2024; Preskill, 2018; Gonçalves *et al.*, 2024).

Secondly, the new paradigm favors democratic decision-making. Quantum technology platforms have the ability to merge vast amounts of citizen feedback in real time, building consensus-based urban policies that align with various community agendas instead of merely following the majority rule doctrine (Thompson and Lorne, 2023; Jiang *et al.*, 2022a). The aspirations of quantum urbanism are confronted by serious practical and ethical hurdles that must be addressed to reach their complete potential. The technology for quantum computing is in its early stages, with poor qubit stability and scalability, which provokes essential questions regarding the potential implementation of such systems in resource-scarce urban settings (Xu *et al.*, 2023). This points to a wider problem in the urban governance structures regarding whether cities are able to implement advanced technologies in an effective way, particularly where infrastructure is absent or non-existent (Criqui, 2015).

Furthermore, fears about the lack of transparency of quantum algorithms refer to the risk of “black box urbanism”, in which decision-making is not transparent and accountable (Robins and Baumgardt, 2024). This kind of transparency deficiency may result in skewed outcomes, especially if the data used at the core of model development are not adequately verified for fairness and representativeness. For example, a quantum model for maximizing economic efficiency may overlook the requirements of marginalized

groups and exacerbate differences in the urban resource distribution that already exist (Voskamp *et al.*, 2017). This relates back to arguments in the literature concerning the nexus between socioeconomic factors and urban planning decisions, which are employed to reproduce or resist urban inequalities (Liang *et al.*, 2023).

VIRTUAL LAND AND NFTS: A NEW ECONOMIC PARADIGM

The concept of land ownership has been significantly altered due to advances in virtual worlds and blockchain. Virtual land, represented by digital parcels on metaverse platforms, is a new asset class that leverages non-fungible tokens (NFTs) to verify ownership and facilitate global transactions. In contrast to physical real estate, which is limited by geographical physicality, virtual land exists in a world of code where value is derived from algorithmic proximity, platform compatibility, and the possibility of rich experiences, such as digital shopping spaces and participatory cultural activities (Alvarez León and Rosen, 2024). NFTs provide transparent and immutable ownership records, allowing open access to this emerging market. They enable a range of actors ranging from individuals, businesses, and decentralized autonomous organizations (DAOs) to speculate, create, and monetize virtual assets. This is attested to by the rise of virtual art museums within blockchain-based metaverse platforms, which serve as places for NFT artwork exhibition, the hosting of global conferences, and experimentation with user-driven economies that merge entertainment and commerce (Nurjaman *et al.*, 2022).

Yet the boom in NFT virtual real estate raises pressing questions about equity and sustainability. As open as the metaverse is touted to be, access is organized around technological literacy, cryptocurrency, and energy grid capacity. The energy cost of blockchain transactions, particularly proof-of-work protocols, contradicts the sustainability goals many virtual environments commit to. Furthermore, the lack of regulatory frameworks for virtual land has generated speculative bubbles, where prices become detached from utility, a phenomenon dating back to earlier land rushes, but driven by global, 24/7 markets. However, experimental projects are closing these gaps. Solar-powered blockchain networks, for example, are reducing carbon footprints, while DAOs are experimenting with redistributive models, such as setting aside land NFTs for public goods or subsidizing access for marginalized communities. These developments suggest a future in which virtual land economies may play a role in achieving Sustainable Development Goals (SDGs) 9 (infrastructure development of the digital kind) and SDG 11 (making communities inclusive), depending on whether they prioritize ethical design over profit-making extraction. Finally, the relationship between NFTs and virtual land is more than a simple financial innovation; it is a model for remapping ownership, governance, and value creation in an increasingly digitized urban space in an age when the lines between physical objects and digital copies blur, allowing every person to shape the cities of tomorrow, pixel by pixel.

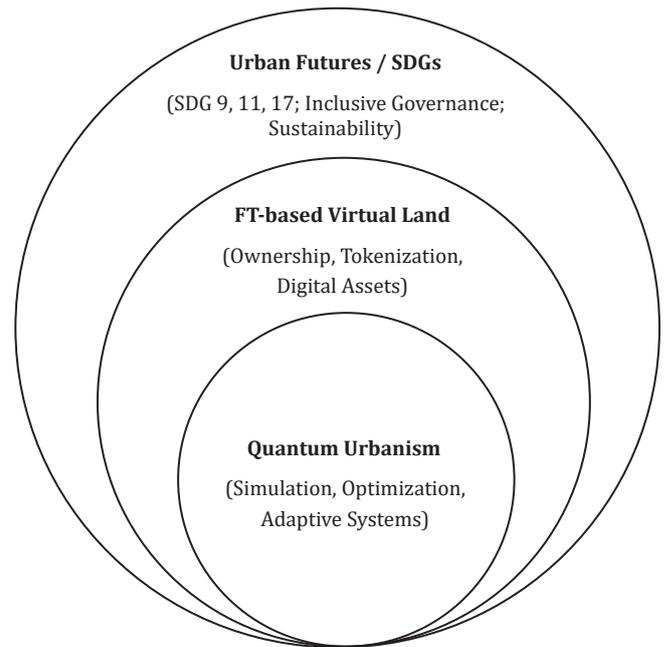


Figure 1. Conceptual framework: Intersection of quantum urbanism and NFTs in shaping urban futures

Figure 1 shows a conceptual visualization of the synergistic integration between quantum urbanism's computational power and NFT-based ownership models, driving towards sustainable and inclusive urban futures aligned with key Sustainable Development Goals.

SYNTHESIS: BRIDGING QUANTUM URBANISM AND NFTS

As visualized in the conceptual framework (Figure 1), the intersection of quantum urbanism and NFTs is a revolutionary synthesis, wherein the computational power of quantum systems meets the decentralized ownership frameworks of blockchain to reshape urban futures. At this intersection, quantum algorithms operating on large, networked datasets enable dynamic simulations of virtual spaces, and NFTs validate and commodify digital properties. This creates a two-way interaction between predictive analytics and the market's real-time behavior (Balcerzak *et al.*, 2022). Imagine a virtual city where land plots, as non-fungible tokens (NFTs), are being constantly appraised not just on the basis of user demand, but also guided by quantum models simulating traffic flow, energy consumption, and social interaction under different scenarios. These systems might automatically adapt zoning regulations or infrastructure plans, with every algorithmic choice immutably documented on the blockchain, building transparency and confidence in decentralized governance (Bai *et al.*, 2022; Treiblmaier *et al.*, 2020).

This synthesis allows urban spaces to arise as adaptive ecological systems. For instance, a quantum-enabled system may optimize the placement of virtual schools, parks, or shopping malls based on analyzing real-time streams of IoT sensor data and user activities, and then mint NFTs representing ownership of the optimally located digital assets (Sifah *et al.*, 2020; Khan *et al.*, 2020). These NFT owners could influence city policies through decentralized autonomous

organizations (DAOs), where quantum-processed consensus protocols balance stakeholder contributions without centralized authority. This is democratizing city planning so that various stakeholders, regardless of geographic and socio-economic divides, can shape virtual neighborhoods through tokenized voting rights (Crandall, 2023; Wong *et al.*, 2022). Blockchain technology effectively enhances the engagement of citizens and enables smooth governance in such smart environments (Jiang *et al.*, 2022b; Gloerich *et al.*, 2020).

However, this convergence is not without friction. Quantum processing and blockchain network energy density have a paradox: technologies designed to enhance sustainability would entrench carbon emissions unless they are founded upon renewable energy foundations. Moreover, the “black box” legacy of quantum algorithms risks concealing decision-making processes and disenfranchising communities that lack technical expertise. In response, hybrid governance models are emerging, blending quantum-enabled efficiency and AI explainability platforms that translate complex simulations into actionable intelligence for NFT holders. Some of the initial pilots, like decentralized metaverses with quantum annealing used for land-use disputes, promise the potential for equitable distribution of resources, and NFT-backed carbon credits catalyze green infrastructure investment in both virtual and real environments.

Finally, the convergence of quantum and NFT is also more than technological advancement. It envisions cities as living laboratories wherein computational intelligence and decentralized ownership spawn resilience, inclusivity, and creativity. By combining quantum urbanism’s predictive capacity with NFTs’ potential for tokenizing engagement, this framework drives Sustainable Development Goals SDG 9 via digital infrastructure innovation, SDG 11 by building resilient urban systems, and SDG 17 via cross-domain collaboration. The challenge is in having these technologies put human-centered design, ethical transparency, and environmental balance at their center, or else they will merely reproduce old injustices in hyper-digitized versions. At this juncture, the task is not only to build wiser cities, but to reimagine citizenship as such, where every individual, with a quantum-enabled NFT, is a co-architect of the space where they reside, be it physical or virtual.

CHALLENGES AND ETHICAL CONSIDERATIONS

The marriage of quantum urbanism and NFTs, as exciting as it is, reveals a maze of technical, social, and ethical challenges that require immediate attention. Top among them is the energy paradox: quantum computing and blockchain technologies, both celebrated as game-changing, come at a tremendous environmental price tag. Quantum processors demand extreme cooling infrastructure, and numerous blockchain networks, especially those using proof-of-work consensus, consume energy at levels rivaling small countries. This imbalance imperils the potential to promote Sustainable Development Goals (SDGs) like affordable and clean energy (SDG 7) and climate action (SDG 13), unless emerging innovations in the form of carbon-neutral quantum data centers or proof-of-stake blockchains become mainstream.

Indeed, the sheer pace of obsolescence of the hardware combined with the extractive mining of rare earth minerals that go into quantum chips imperils exacerbating global inequalities further, where the poorly endowed regions suffer most from environmental degradation. Just as pressing is the digital divide that such technologies perpetuate. Quantum-empowered government and virtual property ownership presume equal access to broadband internet, smart devices, and crypto literacy a situation far from becoming real for underprivileged groups. For instance, while a DAO in a metaverse can decentralize decision-making among NFT owners, it excludes those who are unable to purchase or interact with digital wallets, effectively replicating historical patterns of spatial exclusion in virtual space. This raises ethical concerns about who benefits from “decentralized” urban futures and who is rendered invisible in algorithmic governance.

Furthermore, the opacity of quantum systems also renders accountability more challenging. The formulation of urban policies through quantum simulations, which often confound even specialists, may lead to a diminishment of citizen agency concerning the environments they occupy. Should a quantum model emphasize energy efficiency, it could inadvertently marginalize low-income communities if biased training data is not properly regulated, thereby integrating systemic inequalities into the foundational programming of smart cities. The speculative character of NFT-based virtual land markets adds another dimension of peril. Prices tend to mirror hype, not usefulness, forming bubbles similar to the 2008 housing bubble, but with even less regulatory protection. Unprotected investors who are enticed by visions of “decentralized wealth” could experience disastrous losses when markets adjust. Further, the immutability of blockchain transactions makes error correction more difficult: a misplaced decimal in a smart contract or an erroneous prediction by a quantum algorithm could irrevocably reshape urban environments without remedy. Privacy issues also lurk on the horizon. Quantum computers’ potential to decrypt current encryption techniques threatens the safety of sensitive city information, from citizen biometrics to infrastructure blueprints, and NFTs relating to virtual land can expose users to surveillance or exploitation by corporations harvesting behavioral data. Ethically, the merging of quantum urbanism and NFTs questions fundamental concepts of human agency and cultural sovereignty.

With cities becoming more dependent on AI-quantum hybrids for system optimization, there is a risk of boiling urban existence down to measurable terms, with efficiency over spontaneity, creativity, or shared traditions. Virtual land markets also threaten to homogenize cultural landscapes as global speculators remodel digital territories into profit-driven designs rather than being driven by local identities. Indigenous communities, for instance, may experience the commercialization of their digital representations as NFT art without prior consent or financial remuneration, reflecting longstanding trends of cultural appropriation. Addressing these difficulties requires a multi-disciplinary approach. Policymakers must collaborate with technologists to develop architectures that impose energy

transparency on quantum-blockchain environments, apply antidiscrimination policies on algorithmic management, and protect vulnerable populations within virtual land markets. In addition, ethicists and urban planners must prioritize participatory design to ensure that excluded communities are given a direct hand in shaping the tools that drive their digital-physical spaces. It is only through such watchfulness that the quantum-NFT relationship can avoid being a new frontier of exploitation and instead fulfill its promise as a driver of equitable, sustainable urban change.

POLICY AND FUTURE DIRECTIONS

The future-making promise of quantum urbanism and NFT-based virtual land economies depends on forward-thinking, adaptive policymaking that weighs innovation against ethical guardrails. To unlock these technologies for equitable and sustainable urban futures, governments, multilateral organizations, and communities need to work together in developing frameworks that manage technical risks while promoting inclusive growth. An essential place to start is the creation of dynamic regulatory sandboxes where cities can experiment with quantum-NFT integrations in controlled environments. For example, local governments may collaborate with blockchain consortia to pilot decentralized land registries based on quantum-resistant cryptography, providing protection against future cyberattacks while optimizing property rights management.

At the same time, global organizations such as the UN-Habitat or the OECD need to develop standards for cross-border virtual land transactions, avoiding tax evasion, speculative exploitation, or the loss of local cultural identities in virtual environments. Energy sustainability must be embedded within these policies. Legislation must mandate carbon auditing of blockchain networks and quantum computing facilities and tie operating permits to auditable renewable energy use a theme adapted from the EU's Carbon Border Adjustment Mechanism. Tax incentives for solar-run quantum data centers or NFT platforms using proof-of-stake consensus may accelerate green technology transitions. Equally essential are policies to bridge the digital divide. Public-private partnerships could underwrite participation in quantum literacy education and decentralized identity wallets to ensure that marginalized communities are not left out of virtual land economies. Barcelona's "Digital Sovereignty Plan", with its focus on citizen-driven data cooperatives, offers a template for constructing equity into technology-driven urbanization.

Going forward, research must emphasize interdisciplinary innovation. Universities and technology centers must create quantum-urbanism labs in which physicists, planners, and ethicists work together to co-design algorithms that encode fairness into city simulations, for example, by auditing training data for bias against informal settlements or by prioritizing climate resilience in virtual land valuation models. Meanwhile, decentralized autonomous organizations (DAOs) that oversee metaverse platforms must adopt hybrid governance structures, merging AI-powered efficiency with human oversight to prevent algorithmic tyranny. Pilot initiatives, such as Nairobi's "Quantum Slum Redevelopment Project", which utilizes NFT-based

crowdfunding to develop informal settlements without disempowering the community, illustrate the potential for grassroots innovation. International cooperation is imperative. Just as cities come together under the C40 Climate Network to fight emissions, a "Decentralized Cities Coalition" might exchange best practices in NFT zoning regulations, quantum infrastructure standards, and digital rights to citizenship. Such coalitions would further SDG 17 (Partnerships) while preventing fragmentation in virtual urban environments. Artists, activists, and Indigenous leaders, meanwhile, need to be empowered to inform metaverse cultural policy to make virtual land represent humanity's diversity instead of corporate monocultures. Lastly, the future demands humility. Policymakers must acknowledge that quantum and blockchain technologies are not silver bullets but tools to be wielded with prudence. By placing human dignity, ecological balance, and participatory design at the forefront, cities can evolve into cohesive, adaptive networks where physical and virtual spaces exist as equal, sustainable, and creative expressions of collective desire.

CONCLUSIONS

The intersection of quantum urbanism and NFTs heralds a revolutionary era in city design, one where cities transcend physical boundaries to evolve into adaptive, inclusive, and creative ecosystems. By integrating quantum computing's unparalleled capacity to simulate hyper-complex systems with blockchain's decentralized ownership models, this intersection reconfigures how cities are designed, governed, and lived. Virtual land, represented in NFT token form, presents itself not only as a digital commodity but as an inclusive platform of engagement for global citizens enabling grassroots innovation in commerce, governance, and culture. Meanwhile, quantum urbanism's probabilistic frameworks beckon planners to embrace uncertainty, optimizing cities as living systems that learn from failure, privilege equity, and evolve in synchronization with ecological limits. Yet, this vision remains fraught with paradoxes. The same technologies that offer the hope of democratized access to urban development risk amplifying energy consumption, algorithmic opacity, and digital divides if employed without ethical oversight. The virtual land markets' speculative allure, if left unchecked, can further solidify socioeconomic divides rather than transcend them. Similarly, quantum systems' capacity to outpace human accountability needs to be safeguarded against the erosion of civic agency.

Yet, these obstacles are not inevitable. They call for collaborative efforts across disciplines bringing technologists, policymakers, and communities together to incorporate transparency, sustainability, and justice into the very architecture of next-generation cities. Standing at this crossroads, history's lessons are clear: urbanization's worst failures have been spawned by placing efficiency over humanity, growth over resilience. The quantum-NFT paradigm offers a chance to re-write this narrative, but only if its tools are wielded with foresight and humility. By tying innovation to the Sustainable Development Goals promoting sustainable infrastructure, inclusive communities, and global partnerships cities can leverage

these technologies to widen access to opportunity, enhance cultural diversity, and restore the broken connections between urban habitats and natural ecosystems. The way forward is bold experimentation constrained by rigorous ethical considerations, so that the cities of the future are not just smarter but more wise cities where every person, with a quantum-aware NFT or a contributory stake in a DAO, is included in the stewardship of the commons. It is in this intersection of digital information and physical space, computation and creative culture, that we can imagine urban futures that are both fair and phenomenal.

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