

DIRECTIONS FOR RESEARCH ON INCENTIVISING AND GOVERNING THE INCREASE OF BIODIVERSITY IN CITIES WITH BLOCKCHAIN TECHNOLOGIES

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Abstract

Biodiversity is crucial in sustaining all life on earth. However, extinction of species critical to the functioning of our global ecosystem is a direct threat to biodiversity. The built environment in its urban forms is one of the biggest causes of biodiversity loss through the exploitation of finite resources and land use on which it sits. In this paper we consider the application of blockchain to create new forms of incentivisation and governance for maintaining and increasing biodiversity in cities at the intersection of co-design, blockchain, biodiversity, and design and planning, and propose directions for future research on this topic.

Introduction

Biodiversity is “*the variety of life on Earth and the natural patterns it forms*” (Convention on Biological Diversity, 2009, para. 1). Such variety of species is critical to the functioning of the earth’s ecosystem (Duffy, 2009). However, extinction of species is accelerating faster than ever in human history (WEF, 2020) threatening this variety. Biodiversity loss is reported as fourth in the top five global risks to humanity regarding likelihood and third regarding impact (WEF, 2020). Rockström *et al.* (2009) estimated three planetary boundaries (biodiversity loss, climate change, the nitrogen cycle) that sustain the Holocene and safe operating space for humanity are already exceeded. Global urbanisation, “*the process of anthropogenic transformation of wildlands to the built environment where people live and work*” (2021, p. 125), has accelerated these changes; since 1950, human activity has resulted in more energy use than the entire 11,000 years of the previous Holocene (Elmqvist *et al.*, 2021). As the planet deals with several crises centred on climate change, pollution, biodiversity loss (UN, 2023), and a clash between finite resources and an increasing population (Scheel *et al.*, 2020), a fundamental shift is essential in the relationship between humanity and nature to solve these problems (UN, no date). Being more sustainable is part of the solution, yet not enough is being done to prevent the disastrous impacts they bring (Abbass *et al.*, 2022).

The aim of this paper is to establish directions for research to investigate the extent to which blockchain technologies and smart contracts can be used to create new forms of incentivisation and governance for maintaining and increasing biodiversity in cities. The project will focus

specifically on cities as the areas causing most of the biodiversity loss across the planet through urbanisation (Kirk *et al.*, 2021) and with a spotlight on the urban design and planning phase of the construction lifecycle where the decisions about biodiversity would have the most impact.

In the next section, the methodology for conducting the research for this paper is outlined, then literature on the role of design and planning in constructing the built environment is reviewed. Blockchain as a socio-technical system is presented with consideration to its possible use to govern and incentivise the increase of biodiversity in cities. This is done by analysing literature at the intersection of biodiversity, blockchain and construction through a socio-technical lens. Next, future directions for this research project are discussed before concluding the paper in the final section.

Methodology

In Figure 1 below, the three areas of research interest for this project are shown. There are existing studies at the intersections for two components (e.g., UB and BCT; UB and BE, BCT and BE). However, there is very little research sitting at the centre where all three interest areas intersect (i.e., UB, BCT and BE).

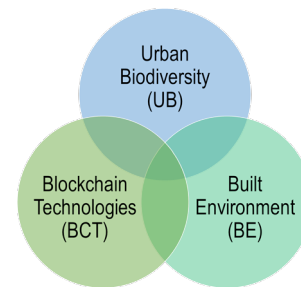


Figure 1: Intersection of research interests

To fill this gap, this paper took an inductive approach to conduct a traditional literature review to establish what is known at the intersections between two or three of the themes above. Given that there is little research at the intersection of all three, the paper suggests directions to fill this gap based on a synthesis of what is currently known.

Literature Review

The built environment’s impact on biodiversity

The construction sector is responsible for constructing

and maintaining the built environment necessary to maintain human life. However, it is also “*known to be the highest contributor*” to climate change (Oguntona and Aigbavboa, 2019, p. 513). Cities are essential to withstand the increase in population density but rapid expansion of urban areas are associated with resultant biodiversity loss (Uchida *et al.*, 2021). Through excessive resource use and adaptation of the land, construction can damage natural habitats jeopardising wildlife and plants. Thus, construction has a responsibility to protect sites and minimise damage to ecology. However, understanding of biodiversity in the sector is poor (Woodall and Crowhurst, 2003) and “*is often viewed as an afterthought or final addition once an urban development nears completion*” (Kirk *et al.*, 2021, p. 1). Biodiversity loss has critical consequences for the human race caused by current methods of production and overconsumption that could see the failure of food systems, collapse of healthcare systems and see whole supply chains disrupted (WEF, 2020). This creates an imbalance of the ecosystems that sustain clean air, water and all life on earth (WEF, 2020). The sector uses a substantial amount the world’s resources from extracted materials, to global water and energy supplies, whilst being one of the highest contributors of greenhouse gasses (GHG) (Wieser *et al.*, 2019). It contributes heavily to the generation of waste and reduction of global ecological integrity, as well as buildings and infrastructure having a long-term environmental footprint (Oguntona and Aigbavboa, 2019). Cities are of strategic importance to the “*global governance of climate change*” and limiting global warming to only 1.5°C (Bulkeley, 2022, p. 266). It hinges on the ability to redress planetary limits and boundaries through reshaping urbanisation (Elmqvist *et al.*, 2021). An estimate puts global temperature increase at 4 degrees by 2100 if governments and the construction sector continue current policies and practices, thus, municipal level decisions are critical to limit the temperature rise to 1.5°C (Miller, 2020).

The role of design and planning in construction

Construction needs to be more sustainable utilising “*a sociotechnical approach, [that] underpins the principle of sustainable development*” (Medaglia and Damsgaard, 2020, p. 3). This can be done in part by moving toward a co-design approach that involves citizens in municipality-level decisions that feed into the design and planning phase of the project lifecycle. Such a concept gaining attention in the creation of the built environment is regenerative design. This positions citizens as both co-creators and contributors of earth’s ecosystems moving beyond the current mindset of resource exploitation without consideration of the consequences (Wang *et al.*, 2023) where quality of life is put before economic growth (Axinte *et al.*, 2019). Camrass (2022) states that urban planners and designers are in a unique position to drive forward the regenerative agenda.

Miller (2020) writes about true democracy taking place in Canadian cities where citizens are regularly engaged with and are part of decision-making at municipality levels

regarding urban planning. Joachain and Klopfert (2011) discuss two complementary currency programmes as policy instruments as follows: NU-Spaarpas was a loyalty card scheme in partnership with independent shops in Rotterdam, The Netherlands to promote greener consumption and behaviour from citizens. E-portemonnee based in Overpelt, Belgium focused on promoting sustainable behaviours by rewarding sustainable actions of citizens. This demonstrates the appetite and necessity for community engagement in promoting more sustainable practices in cities.

Blockchain

Blockchain is rooted in a desire to challenge central elites and associated power structures by offering a transparent, traceable, decentralised and distributed ledger (Ekblaw *et al.*, 2016) that can record anything of value (Mathews *et al.*, 2017). Its decentralised network of computers stores a common ledger and agrees on the truth of transactions recorded on the chain via an algorithmic consensus mechanism. Transactions are recorded on a chain of blocks where each one engulfs the previous blocks' cryptographic hash. It offers security and privacy based on its append-only nature while its immutability provides a single source of truth (Hijazi *et al.*, 2022).

Blockchain has been identified as a socio-technical system by several scholars (Shin *et al.*, 2022; Li, 2023; Selvanesan and Satanarachchi, 2023) who acknowledge society as central to its utility; consideration of this dimension key to its successful adoption. It gave rise to cryptoeconomics – applying cryptography to economic systems for new forms of organisational business models and commons frameworks (Brekke and Alsindi, 2021) – comprised of computer engineering, economics and game theory (Brekke, 2021). Smart contracts are programmable pieces of code that can run on a blockchain and self-execute based on pre-defined logic offering automation to create efficiencies and increase productivity without human intervention. They can facilitate the creation of powerful, domain-specific decentralised applications (Ye *et al.*, 2022). There is concern of the high energy consumption of blockchains, however, this is a misconception for it is applicable only to early blockchains that use the proof-of-work (PoW) consensus mechanism. Alternatives such as proof-of-authority, proof-of-burn, proof-of-capacity and others are very energy efficient (Lashkari and Musilek, 2021). For example, Ethereum originally ran PoW but changed to proof-of-stake in 2022 to consume 99.9% less energy equating to a megaton of carbon weekly (Kessler, 2022).

Blockchain as an incentive and governance tool

Several studies have considered blockchain for incentive and governance systems. Wang *et al.* (2023) discuss blockchain’s potential to govern information, procedures, ownership and values of a regenerative built environment. Zhao *et al.* (2023) present a blockchain-based token incentive mechanism for environmental, social, and

governance (ESG) performance to be used by organisations to attract investors, issue dividends, grant access to products and services, and allocate voting rights. The integration of blockchain, BIM, artificial intelligence, machine learning, building energy management systems and life cycle assessment is proposed by Desmond and Salama (2023) to manage energy usage of buildings. Incentives lie in the trading of stored energy, and smart contracts facilitate tax relief to buildings meeting sustainability objectives. Dounas *et al.* (2022) present a cryptoeconomics-based incentive system centred on architectural design governance connecting building performance and carbon reduction with financial incentives. Incentivising better than net-zero energy buildings are proposed by O'Reilly and Mathews (2019) by storing excess energy generated by solar panels and selling it as a commodity. This incentivises designers to optimise building performance and occupants to behave energy efficiently.

Beyond sustainability-related research, blockchain tokenisation can incentivise changes in human behaviour through decentralisation and offering multidimensional payment systems against today's one-dimensional monetary system (Hunhevicz and Hall, 2020). Hunhevicz *et al.* (2021) employ cryptoeconomics to incentivise lifecycle performance rewarding parties based on performance-based contracts. Green Coin, a blockchain-powered social currency, incentivises citizens to exchange urban waste via a tradable cryptocurrency that can be used in local shops in a Brazilian municipality (França *et al.*, 2020). It helps low-income families, supports awareness of correct ecological behaviours of citizens, reduces landfill waste, and improves health through reduction of fatal diseases such as dengue and zika. A survey on blockchain-incentivised applications across transport, energy and recycling in smart cities is presented in Kahya *et al.* (2021). Finally, in Marsal-Llacuna (2018), blockchain forms the basis of a governance and incentive system to facilitate prioritisation and submission of citizens needs to municipalities leading to the development of bottom-up, citizen-centric masterplans connected to urban codes (e.g., polices, planning, regulations).

Blockchain and biodiversity in research

There are few studies that focus on blockchain and biodiversity and none that intersects with construction. A blockchain-based biodiversity value chain is being developed to manage the unregulated exploitation of indigenous natural habitats (Bose *et al.*, 2019). Blockchain is used in food supply chains to conserve biodiversity through incentivising sustainable practices in agriculture and food waste (Kafi *et al.*, 2023). A literature review finds blockchain can support sustainable forestry, minimise illegal logging and help conserve biodiversity (He and Turner, 2022). The co-design of inter-species relations based on programmable cryptocurrency creates "cities' transition towards Post-Anthropocene for cross-species bio-digital coliving" facilitated by blockchain (Davidova and McMeel, 2020, p. 338). Beyond academic

literature, Greener Tokens (2023) is an initiative that aims to connect companies to restorative finance (ReFi) to protect the Brazilian rainforest. They offer carbon emissions offsetting, ESG project management, and environmental consulting. They avoid greenwashing through their governance framework to ensure true protection of biodiversity. Funded by the Inter-American Development Bank (IDB), the design of digital tokens for a biodiversity innovation challenge aims to preserve natural capital and biodiversity in Colombia, Ecuador, Peru, and Trinidad and Tobago (IDB, 2023). Crypto Altruism (2023) discusses ways in which preservation of natural capital can be incentivised through tokenisation (e.g., carbon offsetting, fractional ownership, preservation of endangered species and the surrounding habitats). Token Kitchen is exploring the preservation of endangered African Forest elephants that support carbon capture and sequestration in the surrounding forests that incentivises locals by issuing tokens upon proof they are maintaining natural habitats (Voshmgir, 2021). Czura (no date) presents three applications: issuing Green Bonds to give investors more control over how their money is invested; TreeCycle that promotes eucalyptus tree planting in Paraguay where investors receive 40% of profits at harvest, 10% goes to local charities and 50% is reinvested into replanting; and the promotion of more sustainable supply chains (e.g., in aquaculture) with a blockchain-based trusted chain of provenance data.

Giving agency to nature, individuals and 'things'

Can blockchain give agency to nature, individuals and 'things' where a thing could be an inanimate object, a system or whole ecosystem? In Athens, Georgia in the United States, there is a 'Tree That Owns Itself' where it was gifted its ownership by the owner of the land upon his death (Figure 2).

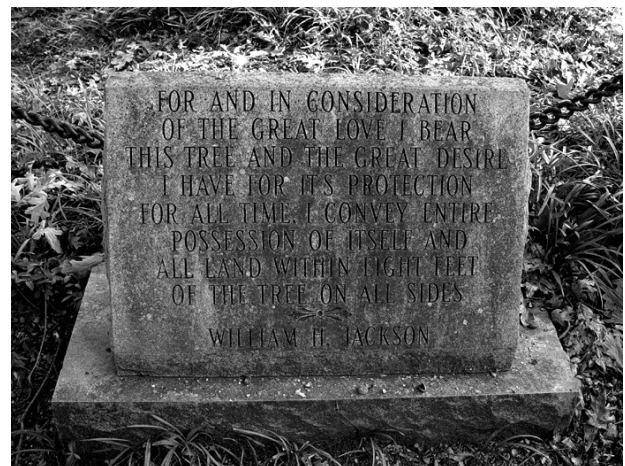


Figure 2: A plaque to commemorate *The Tree That Owns Itself*, "For and in consideration of the great love I bear this tree and the great desire I have for its protection for all time. I convey entire possession of itself and all land within eight feet of the tree on all sides – William H. Jackson" (The Treeographer, 2018)

In a legal sense, the tree does not own itself but nobody disputed the self-ownership and so it was accepted. Upon

the death of the Tree That Owns Itself, an acorn from the original tree was planted in its place where a new oak tree now stands; it is known as ‘The Son of the Tree That Owns Itself’ (The Treecographer, 2018). While this might be difficult to comprehend on a boarder scale, there is research ongoing that allows assets to own themselves in the form of nols1, a blockchain-based project of a self-owned meditation pod at ETH Zurich facilitated by a decentralised autonomous organisation (DAO) (J. Hunhevicz *et al.*, 2021). The University of Edinburgh’s BitBarista project is a coffee machine that accepts payment in bitcoin before administering a coffee to the user and pays people in bitcoin for servicing the machine (e.g., refilling water, cleaning). Individuals buying coffee answer questions about what they want such as high quality, low price, sustainable coffee and so on, the data for which determine the type of coffee BitBarista then automatically orders for itself (McMeel and Sims, 2020). The challenge of giving agency to nature is that nature is limited in its ability to demonstrate intent. According to Schlosser (2019, p. 1), “*an agent is a being with the capacity to act, and ‘agency’ denotes the exercise or manifestation of this capacity*”. Equally, an inanimate object such as a meditation pod is also limited in its ability to demonstrate intent given its lack of consciousness. The DAO is encoded with a set of rules determined by the creators of the pod (i.e., researchers at ETH Zurich). This is of course different to, for example, plants and animals that have inherent intent within the natural order of the ecological system around us, whereas with nols1 and BitBarista, the logic is decided by the humans who created it, whose inherent intent is arguably different.

BitBarista is an example of “*devolved decision-making*” (McMeel and Sims, 2020, p. 215) that we could also call co-design where decisions are made based directly on users’ wants, needs and means. This new form of business model can challenge existing hierarchical decision-making systems that typically benefit the few profiting from those decisions. Smart contracts can be explored for their ability to facilitate agency for nature and things; the challenge will lie in who is given the task and responsibility for establishing intent that is for the greater good and not the profiteering few.

Consolidation of the literature

Consolidating the above literature, the built environment is one of the biggest exploiters of the world’s resources causing substantial biodiversity loss. Current efforts to reduce the negative impacts are insufficient. Therefore, new governance and incentive mechanisms are required to achieve lasting positive impact. Regenerative design aims to bring together different components of the urban ecosystem across the environmental, social and cultural domains with a view to leave the built environment in a better state than it was found. Blockchain could be a solution to bring these elements together as demonstrated by research and initiatives looking to leverage cryptoeconomics for behavioural change. The current efforts of applying blockchain to tackle issues of biodiversity focus on indigenous forests and habitats, and

financial incentives, with very little focus on the urban complex of cities. The subsequent sections consider what can be done through this research project to address some of these challenges.

Future research directions

In this section, future directions for this research project are considered through the lens of the socio-technical framework as set out below. Then it considers initial gaps identified in the literature, and challenges and constraints that will form the focus of the future research before discussing the proposed outcomes.

A socio-technical perspective

A socio-technical framework for implementation of blockchain in construction will form the basis of the theoretical underpinnings for this research project. The framework (Li, 2023) consists of a set of tools and models to support analysis, understanding and implementation of blockchain in construction applications. Its four dimensions of technology, process, policy and society acknowledge the importance of technology whilst giving equal attention to the surrounding ecosystem ensuring any application is developed with a focus on meeting the needs at the social level where benefits are realised.

Technology considers the hardware, software, networks, infrastructure and technological integrations of blockchain-based systems; *process* considers how blockchain will integrate into existing organisational processes and the changes required to adopt blockchain at an enterprise level; *policy* focuses on the regulatory environment surrounding blockchain-based applications regarding standards, laws, compliance etc.; and *society* addresses the impact of blockchain applications on its users and the social environment where benefits will be realised.

Research on blockchain in construction has accelerated in recent years (Li and Kassem, 2021) to propositions of use cases across the built environment with plentiful proof-of-concepts and a handful of applications demonstrated in the ‘real-world’. It is now time to focus the framework on achieving real change not just for the built environment, but for the betterment of humanity. In this paper, an initial evaluation of blockchain’s ability to address the state of urban biodiversity is made. In later work, the framework in its entirety will be applied to better understand the challenges and provide solutions.

Technology: The literature reviewed in this paper has shown the potential of blockchain technologies to facilitate incentive and governance mechanisms that can be directed toward biodiversity. This has been shown by conservation of forests and biodiversity outside of the urban complex (e.g., He and Turner, 2022; Kafi *et al.*, 2023) plus establishment of the several tokens focused on biodiversity in the previous section. The next step is to consider the added complexities of biodiversity maintenance and increase in cities and evaluate how the use of blockchain and smart contracts can facilitate the integration of co-creation in the design and planning phase of constructing the built environment.

Process: From a process perspective, such a re-conceptualisation as co-creation requires re-thinking at several levels including citizen, municipal, and government as well as an understanding of incentives and governance models for urban planners, architects and designers. The organisations integrating blockchain technologies and implementing new business models will need to be aware of the implications blockchain has on existing systems and consider how existing processes will need to adapt or be replaced by new ones. The financial implications of new technologies and business models requires consideration so it is not a barrier to adoption, for this will be a challenge at all scales from micro to meso and macro.

Policy: Policy will be central to the blockchain-based maintenance and increase of biodiversity at the city scale. It is hoped the future findings of this research will inform policymakers on the benefits the application of blockchain can bring to the table. Part of the philosophy of an underpinning blockchain system is the rationale that policy and regulatory frameworks are partly shifted on-chain (i.e., to the computing protocol). As such, diligent care needs to be taken on forming the policies that drive the design of the blockchain and related smart contracts. A key question that would be interesting in the formulation of such policy is the governance rights that might be attributed to nature itself. Other researchers have raised the question as well. However, the use of a particular question as a case study might help us make inroads into forming such policy, even outside the blockchain frame. Beyond policy, of course, there is also the issue on how nature might be able to exercise such rights, so it is not only a question of agency but also of practical execution of such agency.

Society: Biodiversity has implications for humans that make up society. Unfortunately, the activities that we as humans have become accustomed to, to live comfortably and enjoy day-to-day living have negative effects on the environment and result in biodiversity loss. For blockchain as an initiative to incentivise and govern biodiversity maintenance and increase requires: a) acceptance of blockchain as a facilitator, and b) comprehensive participation of citizens in the co-design process to achieve this. This requires establishing what the role of citizens will be in maintaining and increasing biodiversity at the city scale. It is a departure from today's limited participation in municipal governance so will require adjustments from both citizens and municipalities.

Initial gaps in the literature

While there is literature on blockchain-based incentives and blockchain-based governance, the biggest gap lies in a general lack of research on biodiversity at the city scale facilitated by blockchain. While the initial motivation for this research lies with the increase of biodiversity without a specified utility, there might also be another unexpected shift that can directly benefit the economy and production of the built environment. This is the fostering of an environment where bio-based materials and bio-based processes for construction are being adopted within

frameworks of the circular economy. An increase in biodiversity could be coupled with an increase of more readily available bio-based construction materials, directly contributing to the circular economy of the built environment, not only in the financial sense but also in the ecological sense (i.e., in a systemic change).

Challenges and constraints

While the challenges and constraints of blockchain-based governance and incentive mechanisms to maintain and increase biodiversity at the city scale are scattered throughout this paper, this section brings them together to concretise the focus of the wider research project going forward.

- Acceptance of blockchain as a viable solution is required, acknowledging that selling 'blockchain' as the underpinning technology is not the way to do this. The benefits brought about by building on blockchain platforms will offer new propositions, business models, and revenue streams that can be reaped not by marketing a blockchain-based application, but by promoting the benefits of the 'killer app' that will be the tipping point for blockchain applications.
- A change in current business models and levels of responsibility at government and municipal levels is required to embrace co-creation with citizens as a genuine and integrated piece of the solutions puzzle.
- A critical mass of participants is needed to make utilising blockchain technologies worthwhile where decentralisation of power (in this instance away from national and local governments) allows true democracy and a focus on the long-term impacts of the built environment.
- There is limited understanding of the importance of biodiversity across the general public. If citizens are asked to co-create new and rethink existing built environments, they must be aware of the importance of biodiversity, what it looks like and the different ways in which it can be achieved. This requires educating the public (i.e., through participatory action research) to highlight the benefits of bringing back biodiversity to cities such as improved physical and mental health, lower levels of pollution, better use of resources, and more sustainable urban environments.

Proposed outcomes

This research will create a framework to facilitate increasing biodiversity at the city scale. It will examine case studies from regions around the world that have high levels of biodiversity (e.g., Singapore, Brazil) either through protecting the natural environment or through rewilding back into cities. A set of detailed use cases for governance and incentive mechanisms of blockchain in construction will support the framework and an IT prototype will be created to demonstrate how blockchain technologies can enable this.

The outputs of this research will contribute knowledge to a new area of interdisciplinary research at the intersection of co-design, blockchain, biodiversity and design and

planning in construction with a humanitarian focus.

Conclusions

Biodiversity is crucial to the survival of humanity and is central to the ecological systems in which the built environment exists. However, the built environment has evolved in recent decades to one that exploits natural resources and damages the environment without sufficient regard to the long-term effects. The aim of this paper was to consider the potential of emerging blockchain technologies to mitigate the negative impacts of the built environment at the urban complex where most of the damage is seen. As such our motivation lies in improving the performance of the built environment in issues of biodiversity, via the exploration of blockchain incentives and governance. We view biodiversity increase in the built environment as a public good, hence it has a very good alignment with the application of blockchain technologies as a socio-technical system for facilitation of governance and incentivisation.

Existing research has been conducted on blockchain as a facilitator of governance and incentive mechanisms showing its potential in changing user behaviours and organisational processes to create efficiencies and promote real democracy. This paper presents early plans for a research project that will create a framework and an IT prototype to utilise blockchain in maintaining and increasing biodiversity at the city scale. It will do this by conducting interdisciplinary research at the intersection of co-design, blockchain, biodiversity, and design and planning of the built environment.

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