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HUMAN-DATA INTERACTION (HDI) AND BLOCKCHAIN: AN EXPLORATION OF THE OPEN RESEARCH CHALLENGES FOR THE CONSTRUCTION COMMUNITY

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Abstract

Challenges for human-data interaction (HDI) have not yet been contextualized within blockchain implementation in construction. In this positional paper, a focus group accepts the EC3 HDI Committee's working definition of construction specific HDI, and identifies technical (immutability, data storage, transparency, system design, integrating technologies), non-technical (ethics, economic models, environmental, political, social), and overlapping (governance, data usage, data analysis, and data control) factors to be considered in the intersection of HDI and blockchain. Those considerations led to open questions for future research efforts – e.g., regarding what data types (and the associated HDI) are suitable when implementing blockchain in the built environment.

Introduction

As the world becomes increasingly digital, the data produced has become a commodity offering value to those capable of analysing them (Monino, 2021). Data exist in two domains, freely offered data (what we knowingly put out into the world, e.g., via social media), and collected data (those that are collected about our online behaviours, e.g., online shopping) (Mortier et al., 2015). These data are being used to make decisions for society across almost all facets of life (Victorelli et al., 2020). In the construction sector, a digital data-intensive transformation across project and asset lifecycles exploiting the many existing and emerging technologies is underway (Wang *et al.*, 2022). With such an increase in the amount of data produced, understanding how humans interact with them is paramount (Regona *et al.*, 2022). Human-Data Interaction (HDI) is an emerging concept that moves a step beyond Human-Computer Interaction (HCI). HCI is "*the interactions between humans and computers-as-artefacts*" (Mortier *et al.*, 2015), where an artefact represents a digital device interacting with humans. As computing and digitalisation become increasingly ubiquitous, focus should be on how individuals interact with the data of technological systems rather than hardware or software artefacts.

One emerging technology that has major implications for HDI is blockchain. As a socio-technical system (Li et al., 2019), blockchain is an emerging technology for the construction sector that promises to change the trust relationship between actors. Blockchain is a platform for managing and processing data that are often either generated by human interaction or are used for human interaction at a point in the future (e.g., through decision-making based on data that are on or processed by the blockchain and/or blockchain-based smart contracts). While there is a wealth of literature in the field of blockchain in construction (Li and Kassem, 2021), research on HDI and blockchain is limited, and so too is its focus on the construction industry. While not explicit, there are small number of studies emerging that consider HDI and blockchain, for example, Becherer et al. (2020) pose that blockchain is potentially capable of leveraging big data for the capabilities of humans by offering a source for trusted data. Blockchain can potentially shift HDI to the end-user's benefit (offering them more control on data and digital assets), but to achieve this it also introduces new properties (e.g., immutability, transparency), that may need the development of new skills (e.g., private key handling). Another study discusses the interaction of humans and digital twins and while they do not refer specifically to data in this exchange, it does consider the different roles and responsibilities for the humans and the digital twins (Agrawal *et al.*, 2023). Between them sits the data that will facilitate this exchange and integration to serve the construction industry.

The objectives of this positional paper are thus: (1) to explore the current level of understanding of HDI for blockchain in construction; and (2) to empirically generate potential future challenges for research on HDI and blockchain in construction. To achieve these objectives, the paper reports on the findings of an online exploratory focus group made up of expert researchers in the field of blockchain and construction.

In this paper, blockchain and its main characteristics are first introduced. This is followed by an introduction to HDI, discussion of its definition and open challenges found in literature. Next, the intersection between blockchain and HDI is discussed before presenting the results of the focus group. Finally, conclusions are drawn.

Blockchain

Business models, applications and processes can be potentially disrupted by the emergence of blockchain and other distributed ledger technologies (DLT) (Maciel, 2020) – however, there have indeed been some overinflated expectations of blockchain (Froehlich *et al.*, 2022). Nonetheless, while use cases beyond prototypes and pilots are not common in the built environment (Liu, Han and Zhu, 2023), and the efficacy of those technologies can vary across use cases that do exist in other sectors (Calandra *et al.*, 2022), there is indeed an increased interest on such a disruptive potential for construction (Sadeghi, Mahmoudi and Deng, 2022). This paper does not intend to provide a detailed technical overview of blockchain (as can be found in, e.g., Perera et al. (2020) and Hunhevicz and Hall (2020)). However, a brief overview is provided.

Blockchain is a peer-to-peer system for value transactions that uses a shared, decentralized digital ledger that is replicated across various nodes (Lamb, 2018). It is claimed that this system eliminates or substantially reduces the need for third-party intermediaries for transaction verification, security, and settlement (Singhal, Dhameja and Panda, 2018). Every digital entry is either permanently immutable or, in special systems, temporarily immutable (Dorri *et al.*, 2021), and any new ones are replicated in all database replicants housed in the nodes (Singhal, Dhameja and Panda, 2018). These nodes are configured according to the blockchain's privacy settings, which results in various digital topologies, from public permissionless systems to private permissioned ones (Chong *et al.*, 2019). Certain blockchain topologies allow for "smart contracts", i.e., computer protocols for facilitating, verifying, or enforcing decision or contractual clauses (Cuccuru, 2017).

Blockchain allows data transactions to be recorded in a decentralized and transparent storage (Verhoeven, Sinn and Herden, 2018). This record's "blocks" each contain limited data, after which they are linked together in a predetermined sequence (Verhoeven, Sinn and Herden, 2018). Therefore, by resolving the block transactions, blockchain not only contains the information about the most recent ones, but also the entire history (Verhoeven, Sinn and Herden, 2018). This is shared across all nodes and can only be updated by consensus using specific validation techniques, such as "proof-of-work," "proof-of-stake," and "proof-of-authority" algorithms (Rossi *et al.*, 2019).

Defining Human-Data Interaction (HDI)

Victorelli et al. (2020) discuss HDI in terms of the manipulation and comprehension of big data sets, with a focus on personal data and their implications regarding decision-making and action-taking. Mortier et al. (2015) discuss three HDI aspects: legibility, agency and negotiability. *Legibility* is being able to understand the data and its processing, as well as ensure its transparency. *Agency* is being able to opt in or out of data systems, as well as control and amend one's data. *Negotiability* refers to relationships between data and their processing – including the regulatory environment, societal norms and the individuals' changing attitudes regarding personal data.

Despite such attempts to describe HDI, a definition of this nascent concept in construction is not yet established. However, a *working* definition has been proposed by the HDI Committee of the European Council for Computing in Construction (EC3) in their seminal white paper: *"HDI is about understanding the interactions between actors and data across the planning, design, production, operation, and use of built assets, in order to improve the outcomes (e.g., economic, environmental, and societal) and value of data to the involved and the affected actors"* (Kassem and Kifokeris, fo.).

Open challenges for HDI in literature

Open challenges for HDI in the context of design include addressing how individuals are made aware of, access, and change and/or improve data; involving end users in the design process for the cocreation of data consumption environments (with a focus on suitability and meeting the users' needs); addressing policies and ethics of data ownership; and effectively visualising data to support decision-making (Victorelli *et al.*, 2020). Mortier et al. (2015) focus on the challenge of economic value being obtained by the actors exploiting the data rather than the data owners, and the misalignment of power around data ownership. The need to conceptualise pragmatic and social issues when considering the social impact of data is raised as an open challenge by Hornung *et al.* (2015), stating that HDI should enable "*stakeholders to promote desired and avoid undesired consequences of data use*". Calvetti et al. (2021) identified several HDI challenges in sensored construction sites, including data ownership and separating between data analysis of the task or the individual; General Data Protection Regulation (GDPR) and informed consent of individuals for data collection; and individuals' trust in HDI systems with regards to possible misuse of data. The latter study is the only one to identify HDI challenges in, specifically, construction.

The intersection between HDI and blockchain in the context of construction

Given the limited literature on the topic, to understand the intersection between HDI and blockchain, a focus group was conducted to explore what the key aspects of HDI are for construction and how the characteristics of blockchain impact upon HDI and vice versa. Given the aforementioned nascence of the concept of HDI and the relative nascence of blockchain, in that there are very few real-world applications in construction today, the focus group served to identify key challenges between these two elements and propose direction for future studies.

Focus group

This study was inductive in nature and consisted of empirical investigations through an online exploratory focus group comprised of eight academics from across Europe. Table 1 shows the profile of the participants. The focus group was facilitated by an online collaborative white board (Miro) and video recorded for subsequent transcription.

Participants were first asked to consider the definition of HDI proposed by the EC3 HDI Committee. It was accepted by all focus group participants as fit-for-purpose and was, therefore, adopted for this paper. Next, participants were presented with the open challenges of

Table 1: *Profile of focus group participants*

ID	Role	Specialisation	Location	Experience in blockchain research
P1	Senior Scientist	Integrated planning, industrial building	Austria	6 years
P2	Asst. prof.	Industrialised construction	Netherlands	5 years
P3	Lecturer	Blockchain, construction management	Netherlands	6 years
P4	Asst. prof.	Construction management, production, blockchain	Sweden	5 years
P5	Post-doc researcher	Blockchain, construction management, digital fabrication	Switzerland	5 years
P6	Assoc. prof.	Smart buildings, smart cities		3 years
P7	Asst. Prof.	Internet of Things	Canada	5 years
P8	PhD Candidate	Smart contracts, contract management	UK	3 years

HDI as identified in literature and discussed above, and the characteristics of blockchain such as those identified by Li *et al.* (2019). Discussions for the remainder of the focus group centred on what the participants understand by the term HDI, what the aspects are that need to be considered for blockchain, which of those are applicable to construction and what the research challenges of the intersection of the two are. The results of the focus group are presented below.

Thematic analysis

Following the focus group, the video recording was transcribed and thematically analysed following Williams and Moser's (2019) three-step coding. The data were coded into technical and non-technical factors of blockchain and HDI considerations. Moreover, some codes that were attributable to both technical and non-technical factors were eventually referred to as 'overlapping factors'. The resulting themes are shown in Fig. 1 and discussed in the following.

Technical factors

Data immutability is potentially one of blockchain's key properties with a use for construction, especially regarding historical data, information management, communication, and dispute resolution. However, corporations exploiting human data is an open HDI challenge. With blockchains, "*once [the data are] there, you cannot delete them anymore. Or at least maybe you can update them, but you cannot remove the trace*" (P5). Web3 offers a rethinking of current data collection and processing "*emphasising the new kind of own part of the read, write, own paradigm*" (P2), with individuals retaining control.

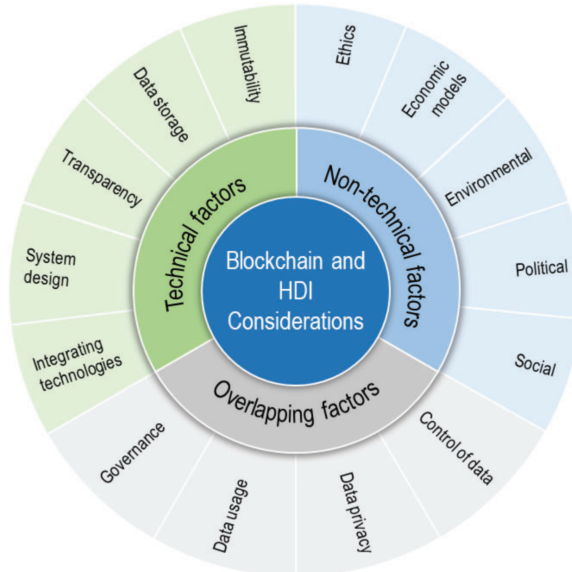

Figure 1: Blockchain and HDI considerations

Immutability is closely linked with on- or off-chain ***data storage***. On-chain storage raises issues of immutability contrasting GDPR's right of erasure, as well as of storage size limitations. Off-chain storage raises issues of data security on, e.g., common data environments (CDEs) and the InterPlanteary File System (IPFS). While the latter can comply with GDPR, the on-chain data proof may no longer exist off-chain if it has been erased under GDPR. The way GDPR and other data privacy regulations might apply to Web3 projects (with implication for blockchain and HDI) is schematically shown in Fig. 2.

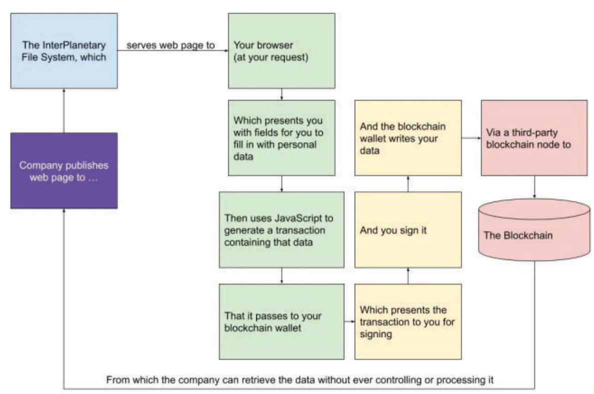

Figure 2: GDPR and other data privacy regulation as they could apply to certain Web3 projects (Finlow-Bates, 2022)

Transparency can also be linked to immutability and data storage, as all those factors are required to provide transparency in a blockchain. Where we need to see "*changes in the model or something like that*" (P1) during the design phase, the data linked to such activity is essential for the human element of who did what, when. So, while GDPR requires informed consent, right of access, right of erasure etc., there will be circumstances when these elements may not apply or be required. P8 discusses a contract management scenario where "*a defect takes place after seven years from the completion of a built asset so the causes or the actors that were involved with regard to that specific defect need to be identified around defects and liability*". In such a case, the human whose data would be collected, processed, and stored "*wouldn't be able to sign that contract*" (P3) and the work would be contracted to someone who would agree that their data cannot be erased.

As blockchain and smart contracts can potentially be used by anyone intending to create value, good ***system design*** becomes imperative ("*it's actually very important to design the system right*" (P5)). From an ethical stance, this would mean not exploiting the human users; however, "*economic value obtained by those exploiting human data*" (P5) is not always done ethically. Regulation such as the GDPR can help; however, incorrectly designing the system could result in, e.g., a situation where "*data that shouldn't be public ends up on a public blockchain, you run into a problem. But if you design the system well, there is actually a possibility that you always stay in control of your data. And you can give and revoke access on your own [data] as many times as you want*" (P5). Part of blockchain governance will relate to the type of structure employed – whether the blockchain is permissioned or permissionless, private or public – and HDI "*will vary across these two types*" (P8). This raises questions around the human-centred data required in construction projects, and whether they need to be on a public ledger or not. A peer-to-peer (P2P) blockchain network facilitates access rights to data between peers, "*which gives you actually more control over where the data goes through*" (P5). This contrasts with traditional systems where data "*go through an external service and you don't have really a lot of control*" (P5). Nonetheless, as data must be reliable in the first place, the issue of data origin integrity can also be raised in connection to system design.

Data immutability should also be considered when using human data that has been collected, processed, and utilised by ***integrating technologies***. Blockchain can potentially be integrated with artificial intelligence (AI) or machine learning (ML) algorithms for decision-making and future predictions. An issue could then arise when data that drive decisions are embedded with "*racism and biases and things like that, because that's the real world*" (P3). Those biases should not enter blockchain-based systems, where due to immutability it would be difficult to rectify. There are also additional considerations on integrating technologies concerning data types and interoperability as well as hardware and software interfaces with, e.g., the Internet of Things (IoT) and construction-specific technologies such as Building Information Modelling (BIM), digital twins and industrial construction robotics when integrated with blockchain. This raises challenges around data fusion where data are collected from different sensors and oracles across construction sites within these systems that support decision-making.

Non-technical factors

Ethics is a crucial aspect of handling human data. It has gained prominence after corporations have been revealed to commercially exploit data collected from individual users over the Internet. Immutability becomes an issue when human data are not treated ethically by those who collect and process them, especially under an economic model which is itself exploitative; blockchain offers "*even more ways to tokenize and sell data and make money out of it*" (P5). Moreover, AI/ML algorithms that internalize (due to design and development flaws) issues such as biases and racism can still affect blockchain systems they are integrated with; data that is ridden with biases beforehand will be passed over into blockchain, even if the algorithms are not necessarily executed on the blockchain platform. However, blockchain itself is another tool that humans can use to address ethics from a processual (rather than social) perspective – and can do that by suitably designing and implementing smart contracts pre-defining some (ethical) rules of operation in a blockchain system (e.g., by filtering out certain types of data that have been flagged as malicious).

Blockchain was developed to challenge centralised (and as such, hierarchic) ***economic models***. Blockchain can potentially challenge centralized power over data. It allows consideration of "*how to incentivize differently, what kind of transaction costs are happening, […] what would be some of the impacts?*" (P1). Ensuring any blockchain system is designed as intended and not (economically) exploiting human users, "*the implications of such things and the unintended consequences of such decisions*" (P2) should be considered. There is "*a choice with this new technology, do they want to monetize their data or not? Or do they want to build new economic systems around the data or not? […] it really depends how you design these economic systems*." (P5). This is "*interconnected with the governance system, which means you need to think about who will provide the data, what will you do with the data, how would you view the data?*" (P1).

The intersection between HDI and blockchain in construction can include collecting, analyzing, sharing, securing, and transparently storing data on ***environmental*** and sustainability issues, allowing for improved stakeholder collaboration and decision-making. Specifically, blockchain can be used to promote sustainable practices by creating a tamper-proof record of sustainable materials, energy usage, and waste management. Transparent and traceable supply chains can be created, allowing for the tracking of products from the point of origin to consumption. Thus, there can be an overview on whether products are sustainably sourced and produced, and environmental risks could be identified and mitigated. Blockchain can also be used to create decentralized carbon credit trading systems for mitigating greenhouse gas emissions, where the transparency of individuals and organizations can be improved by HDI's understanding of value (see the definition of HDI previously) – in contrast to current carbon credit trading, where the carbon impact is mostly offset rather than amended, due to opaque business practices and data interactions. It is also possible to create decentralized renewable energy systems, where individuals and organizations can P2P buy and sell renewable energy and maybe reduce their dependence on fossil fuels. Moreover, transparent and traceable waste management systems can be created, allowing for the tracking of waste from the point of origin to the point of disposal – thus encouraging sustainable waste management practices. Decentralized environmental monitoring systems can also be created; data from IoT, sensors and monitoring equipment can be transparently and securely recorded and shared. That way, environmental risks can be identified and mitigated according to environmental regulations. Additionally, smart contracts can be used to automate the tracking and reporting of environmental data and incentivize sustainable behavior among construction companies.

Nonetheless, there are environmental implications of blockchain use, especially due to the energy consumption of mining when proof-of-work algorithms are deployed. The replication of data across many nodes also means that on-chain storage may not be energy-efficient. While those issues may be related to the system design itself, HDI could point to sustainable solutions. For example, materials tracking can incentivize the use of renewables for mining or off-chain data storage, and different HDI levels may point to blockchain topologies not using proof-of-work algorithms (e.g., permissioned blockchains using proof-of-authority consensus mechanisms).

While ***political*** issues (e.g., corruption, mismanagement) can be mostly appointed to institutional factors, the intersection between HDI and blockchain can help mitigate their impact on the construction sector. Transparency and immutability of records on a blockchain can help prevent fraud (especially when HDI is implied, e.g., in public records for contracts of infrastructure projects). When considering HDI, blockchain can also enable the decentralization and democratization of decision-making by distributing power among multiple parties. Furthermore, smart contracts can help automate processes and reduce the need for intermediaries, which can potentially mitigate resource mismanagement, disputes, and delays. Moreover, blockchain-based voting systems could further democratize HDI and decision-making processes in multi-stakeholder scenarios in construction.

However, the political implications of the integration between blockchain and HDI itself should also be considered. In some countries, using cryptocurrencies (and by extension, relevant blockchain systems) is banned. Moreover, GDPR tenets should be constantly checked, as described previously, while there is a lack of policies for other data-related issues altogether.

The intersection between HDI and blockchain in construction can help increase accountability in decision-making and action-taking while addressing ***social*** issues such as population displacement and gentrification. Tamper-proof records of land ownership and property rights can be created, which can aid in the resolution of disputes. This can be especially useful when, e.g., the land is owned by indigenous communities or other marginalized groups, who may be at a higher risk of displacement. The automated execution of smart construction contracts can potentially help to ensure that the rights and needs of affected communities are protected, and to provide transparency and accountability in the use of social project funds. Blockchain can also be used to create decentralized platforms for community participation (through HDI) in the planning and construction of housing, infrastructure, and public spaces. Communities can thus be potentially empowered. Finally, since there are no gatekeepers in the technology, internet access is enough for it to be accessed and used for enacting HDI by all members in the community.

However, it must be noted that the intersection of HDI and blockchain in the context of non-technical issues within construction is still in its early stages, and more research is needed to fully understand the potential implications.

Overlapping factors

A question raised, though not fully answered in this early study, was whether we should consider ***governance*** of a blockchain vs. blockchain as a governance tool. P8 highlights that "*in the construction management research domain, all the proposed frameworks and proof-of-concept systems are for governance by blockchain while there is a lack of governance of blockchain*". The technical element of governance centres on system design (including the interactions between different actors), whereas the non-technical element concerns the way a system is governed. There needs to be distinction "*between what kind of operational process can be always done through technology, or standardised or automatized, and what kinds of activities or processes are not falling into that group […] which only want a human being*" (P1). Decentralised autonomous organisations (DAOs) could offer a solution to the governance (and the HDI within it) of blockchain systems.

Data usage relates to both data types and use. P2 categorised them into individual-level and system-level data: "*I think of individual personally identifiable data when we talk about the issues of HDI. But then at the same time, all those individual data points make up big data. And big data is what drives a lot of decision making in machine learning*" (P3). As such, there are interactions with some of the factors above (e.g., immutability, ethics, system design, traceability, etc.). But this could also relate to "*project data, […] and then you could even say, 'Does product data have the right to be forgotten? Or does it have the responsibility to never be forgotten?'*" (P2), which raises issues of "*data longevity, our future sustainability, and planetary boundaries*" (P2). Interoperability, as an aspect of data usage, can also be a significant challenge when it comes to construction management – as is happening in other technologies, e.g., BIM. It is important to ask "*are those files/data types manageable with blockchain? How are they stored on the blockchain? Are they stored in an encrypted manner? And if they're not, what is the use and the utility of having* *blockchain?*" (P4). Data creation and processing should also be considered, as "*there might be human-generated data on the first level, and then this might be picked up by IoT sensors*" (P4). IoT sensors are designed to function on the human-to-human, machine-to-human, or machine-to-machine levels. So, as data are transferred between human and/or non-human actors it could "*become unintelligible for humans*" (P4) – and at this point, how can a human maintain control of their data?

GDPR has been mentioned several times above – and is also central to ***data privacy***. This varies in blockchains depending on the system design (e.g., permissioned, permissionless, public, private). As described before, immutability goes against the right of erasure in GDPR and has implications for on-chain storage. P7 points out that "*proclaiming for the right to be forgotten in the GDPR is to be supported through the [off-chain] IPFS technology, but not the blockchain and this is the conflict between the blockchain and GDPR*" (P7). Cases of defects in construction projects may render data erasure inapplicable; however, there may be circumstances where this must be complied with (e.g., personal data of past tenants in rentals). Moreover, privacy relates to data legibility, agency, and negotiability. Each element can be satisfied by blockchain, provided the platforms are designed appropriately for their intended use and the associated HDI. P7 explains that "*if the user gives consent, then we also capture such consent inside the blockchain as a new event. If we kept the data inside the block inside of IPFS, and every access to the data through the IPFS will be controlled by the blockchain,*" this will "*satisfy the right of access. And for the right of erasure, it will be supported through the [internet protocol] IP address based on the request by the users*" (P7). This integration with distributed databases (e.g., the IPFS) may be a solution to GDPR considerations for blockchain. However, (a) the historical record that points to off-chain data that may have been erased, and (b) rules about when data is permitted to be erased and when not, should be considered. An individual's request for erasure may not always be permitted and so such instances should be apparent in the governance model.

Like many of the factors highlighted in this paper, ***control of data*** can be linked to system design, transparency, immutability, data privacy, etc. Data control is directly associated with the system's technical design – but its rules for reading, writing, and owning access are established at a process level and based on the intended system purpose. "*Because [blockchain is] a peer-to-peer system, I think there is more control over data by the individual*" and "*if it's a public blockchain, you even have more control because you can actually look up the smart contract, you see the source code, you see what's happening with your data, […] it actually gives you more visibility and control in terms of automation*" (P5). Such control can be written into the system's governance model and the emergence of Web3 can reinforce that for users by "*emphasising the new kind of own part of the read, write, own paradigm*" (P2). Implementing this new form of data control can however be challenged by "*a huge amount of change to what we do at the moment because I don't have control on what's collected on me. And the level of resistance to change in construction is phenomenal. So how do we marry this up?*" (P3).

Open questions from the focus group

Considering the aforementioned analysis, the focus group has considered the following open questions:

- Does blockchain increase the level of HDI in construction? (P2)
- How does blockchain interact with HDI along the intersection of factors mentioned above? (P2)
- What data types (and the associated HDIs) are suitable for blockchain in the built environment? (P4)
- When we say HDI in construction, do we mostly refer to individuals, or larger social groups? (P2)
- Are we looking at how HDI could support the implementation of blockchain in construction? Or at HDI emanating itself from the usage of blockchain in construction? (P1)

These questions are aligned to the open HDI challenges identified in previous literature efforts. However, they are unique in the sense of explicitly referring to HDI implications when blockchain is implemented in the context of the construction industry.

Discussion and conclusions

This positional paper opens the discussion about the intersection of human-data interaction (HDI) and the application of blockchain technology within construction. While the literature has postulated some open challenges for HDI, those have been not contextualized before as above. This was hereby tackled by a focus group analysis. The focus group first accepted the working definition of the HDI committee of EC3: "*HDI is about understanding the interactions between actors and data across the planning, design, production, operation, and use of built assets, in order to improve the outcomes (e.g., economic, environmental, and societal) and value of data to the involved and the affected actors*". Then, the focus group identified technical (immutability, data storage, transparency, system design, integrating technologies), non-technical (ethics, economic models, environmental, political, social), and overlapping (governance, data usage, data analysis, and data control) factors to be considered in the intersection of HDI and blockchain in construction.

The identification of these factors indicates that HDI and blockchain implementation, let alone their intersection, are at their nascency within the context of the built environment. While individual research or practical efforts have been made in understanding and utilising each of the themes, their integration is still underexplored, and widespread use cases beyond pilots, prototypes, or small-scale implementation tests are largely non-existent. This might mean that a coalition of social actors (e.g., users of the built environment, communities, construction sector representatives, legal, regulatory, and governmental bodies connected to construction) should organise, understand, and produce relevant development and use policies in an equitable manner – which follows from the decentralisation and democratisation that is claimed for blockchain to be able to offer through meaningful HDI.

While this study was delimited in that an analysis of only one focus group was conducted, the considerations above did lead to some further open questions for future research efforts. Those include inquiries on whether blockchain increases the level of HDI in construction; the way blockchain interacts with HDI along the intersection factors mentioned above; the identification of data types (and the associated HDI) that are suitable for blockchain in the built environment; the understanding of whether HDI in construction refers mostly to individuals or larger social groups; and whether the research point of view should be differentiated between HDI supporting the implementation of blockchain in construction, and HDI emanating itself from the usage of blockchain in construction.

Other future considerations could focus on exploring Web3 as it can change aspects of human data ownership – where individuals are controllers of their own data and can grant access to other parties under agreed terms allowing them to revoke that access at any time. P6 mentioned "*I think that the real question is whether others still have access to it, because files can be copied as many times as you want. Removing accessibility to it on one system is no guarantee that it doesn't persist on another system. So, it's actually naïve to demand that something needs to be deleted*". This change would require a major rethinking of existing processes and a redesigning of existing systems that would be both costly and challenging to corporations and institutions, which would likely be reluctant to fund such changes.

As a final remark, it is not easy to address the topic of this paper without referring to selected scenarios and use cases for different blockchain applications and types of blockchain. A way forward could be to localise and/or contextualise the aforementioned high-level challenges by running a number of workshops on some selected significant use cases (featuring various blockchain types), in order to develop a more granular analysis of open challenges and research questions for the future.

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