Deciphering CryptoArchitecture: The architectural design studio as a vehicle for exploring the integration between blockchain and architectural design

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Abstract: In this paper we are using the outputs of research led architectural design studios, originally articulated as pedagogical projects at the Edinburgh School of Architecture and Landscape Architecture, University of Edinburgh and the Robert Gordon University in Aberdeen to explore and evaluate the possible transformative effects of blockchain/Decentralised Ledger technologies and decentralisation in the architecture discipline. After describing the pedagogical studio experiments, we frame a classification of relevant thematic clusters, where distributed ledger technologies can be applied to architectural design and thinking. The design studio, is treated as a methodological research tool, appropriate for the identification of existing knowledge gaps around the topic. The emerging classifications in terms of blockchain and decentralisation implementation is used to synthesise a map of future pedagogical and research activity.

Keywords: Blockchain, Cryptoeconomics, Tokenization, Pedagogy, Codesign

1 Introduction

Since 2009 Blockchain has been developed as an infrastructure technology powering decentralised finance (DeFi) and decentralised autonomous organisations (DAO), plus Non-fungible Tokens, NFTs. However, the engagement of architects with blockchain has been minimal, even if the first architecture decentralised organisation, ArchiDAO, has emerged. Employing blockchain in architectural design takes considerable effort in setting up the infrastructure, plus there are very few ready-made tools to interact between blockchains and digital design tools architects use. Thus, for the past two years, we have explored conceptually the application of the technology into architectural design through the means of the architectural design studio in four

architecture schools: University of Edinburgh (UoE,) University of Dundee (UoD), Xi'an Jiaotong-Liverpool University (XTLU) and Robert Gordon University (RGU).

The motivation of the paper lies with exploring the application of blockchain in architectural design and speculating on the impact it might have on architectural practice. The key question that the paper attempts to address is: Given blockchain's transformative features in terms of organizational and structural forms, which vectors does blockchain affect architectural design with? Which are the possible and discrete categories and envelopes of practice where blockchain can be applied into architectural design? In close affinity is the question of the economy of architectural design: Are the structural economic changes that Cryptoeconomics introduce visible in the architectural form produced?

1.1 Background

Blockchain and Distributed Ledger Technologies provide with a technical infrastructure, on top of which other applications can be developed to exchange value, encode conditions, communicate. A basic technical description of Blockchain, Smart Contracts and Cryptoeconomics follows.

Blockchain is a distributed computer network that maintains a decentralised ledger of transactions. The network does not have a centralised coordinating node, but derives consensus using an algorithm that incentivizes computer nodes to correct behaviour, i.e., agreement to a single truth for the ledger. The ledger changes in blocks of information, where each one contains a Merkle tree, (a structure to efficiently verify the integrity of data in a set), of transactions and the cryptographic hash of the previous one creating thus a chain of blocks. Due to the distributed nature of the ledger, the embedding of cryptographic hashes chaining the blocks of transactions and the use of incentives consensus algorithms it is technically very hard for an attacker to change past information recorded on a blockchain. While the first blockchain was invented to maintain a ledger of simple sums and subtractions (bitcoin white paper), blockchains allow the execution of autonomous software classes on them, transforming them into distributed stack computation machines. The software classes are called smart contract due to the implicit guarantee that the code will executed every time as written with no human intervention (Nick Szabo 1994). Consequently, blockchains encapsulate the concept of trust, as agents and parties can record to them information without it ever being changed or deleted, the concept of incentivised participation, i.e., one gets rewarded for contributing to the common pool resources of the system, and the concept of automatic execution of code in the form of smart contracts. These ideas are then the foundation of modern cryptoeconomics, i.e., economic systems where incentives and performance are secured through advanced cryptography of the blockchain. Most economic constructs on blockchain take the form of tokens,

i.e., special smart contracts that represent either some kind of uniqueness, have some utility in specific contexts, represent some value in other contexts. This introduces further the idea of tokeneconomics, which operates on a layer above cryptoeconomics. For example, a particular community might issue their own fungible token that is used for transactions within the community, while another might issue a non-fungible token that grants the holder governance rights over common pool resources or the organizations. In other example tokens might have the function of securities i.e., they represent the ownership of an asset of value, for example a building or a stock.

2 Methodology

2.1 The studio as an investigation field for emerging technologies in architectural design

The paper uses hybrid methods in order to tackle the key research questions. We use qualitative analysis as a framework for encapsulating a rich field of primary data, generated through design methods in four distinct architectural design studios. The four architectural design studios are an undergraduate course in UoE, and three postgraduate courses in UoD, RGU, and XTLU, where design briefs were given to the students with the question of developing a series of exercises: Decentralisation and blockchain technologies in RGU and XTLU, Decentralisation, blockchain technologies and urban analysis and design of systems in bigger scales in UoD, and more elaborate three exercises in UoE. Core to the case studies thus, is the deployment of “research in design”, as operationalised in the architectural design studios, which coupled with the qualitative analysis leads into “research for design” [Frayling 1993] [Rendell 2003].

Christopher Frayling’s foundational paper on research in art and design produced three practical classifications of the types of research that arise from the studio design process; research into design, research through design and research for design. Frayling considers research through design the least straightforward of the three categories but still identifiable, including materials research, development work, and action research. The development work in this context includes the customisation a rethought of a piece of technology to accomplish that has not been explored in depth before and communicate the results.

The paper analyses numerous design projects developed in UoE, UoD, XTLU, RGU. Empirical, grounded analysis of the data generated by the architectural design studios results in the constructivist formation of thematic clusters of interests. We thus avoid the failure of confusing the design practice that has been developed in the design projects with the systemic knowledge

developed through their analysis. [Friedman 2008] The paper also acts as an initial confirmation of the idea that blockchain, beyond the relatively predictable effects as a technological framework for certain aspects of the AEC industries, provides a series of pathways/clusters for future research.

2.2 The conceptual deployment of blockchain in the design studio to frame future research on the topic

All four briefs developed to be explorative and experimental, in the sense that they presented a well laid out table of concepts but did not prescribe types of architectonic output. Instead, students were free to engage with the concept of BC/DLT on the systemic level and develop their own systems, from which then they presented specific output in each studio. Some of the studios had more of a focus on the urban scale such as the ones from UoD and XTLU while others had more of a focus on the architectonic scale and artefact such as the ones from RGU and UoE.

We used then the developed projects as case studies subject to qualitative analysis to frame a classification on how blockchain technologies can affect architectural design. To construct the classification, we employed a discursive method in analyzing the dimensions of the projects but also the knowledge gaps they potentially respond to.

There was knowledge, practical and methodological reasons for these deployed methods. Key orchestration of these were the apparent lack of existing projects, apart from known examples of the authors' research that use blockchain and smart contracts in architectural design. In terms of knowledge, we needed thus to create a field within which to deploy the conceptual understanding of blockchain in architectural design, without the burden of the practical overhead of having to deploy and manage a blockchain ourselves. As such all of the case studies analyzed within the paper remain on the conceptual design level, without a corresponding implementation. This is obviously a limitation and a constraint in terms of validating the full potential impact of the technology on design, however this is a much needed first practical step in framing the discussion so that then we can later deploy the infrastructure to continue our investigation. As such, the present paper is a part of an initial conceptual deployment and discussion that we hope will affect and shape future research.

3 Results

This research uses a combination of critical reflection on design outputs and a systematic review of existing literature to construct two maps: a cluster of themes developed by architectural designers in their early stage of their

careers or during their education, and a map of future research, in synthesizing the findings from the studios while addressing knowledge gaps in the field of DLT/Blockchain in architectural design. The methodological constraints are the limited number of architectural design studios /designers examined so far, and the attempt to examine an early and developing field. The co-relation and overlap between gaps in the design clusters and gaps in the knowledge are also further examined, establishing mechanisms for validation of future research.

3.1 Emerging Classifications

After spending a year supervising the development of the projects and analysing the findings, the identified trajectories where blockchain infrastructure integrates with architectural design and thinking, revolve around a shift in the discipline of architecture towards a non-extractive, collective vision. First of all, the rediscovery of a sustainable vision for the Commons, based on positive incentivisation and a celebration of individual contribution to a collective authorship. Within this strand we observe the re-framing of design as a Commmon Poll Resources Problem, and the subsequent application of the Ostrom Principles on architectural design. This allows the development of resilient and sustainable manner treating design as a collective action, rather than a lone-hero vector. Moreover we see the further promise of the development of decentralised – distributed manufacturing, which includes the condition to democratise and make accessible complex fabrication processes empowering local creators, enhancing the resilience of supply of certain chains and cutting down transportation related emissions. Moreover, these models include bigger operational shifts about the ways that buildings are designed in collective and reconfigurable ways, utilising smart contracts in a way that buildings become the summaries of various architectural vectors, for example connecting digital twins with their physical counterpart, via smart contracts.[Dounas et al – Cryptotwin Ascaad 2022] They also include a possibility for strengthening collaborative design and the manner in which space is produced, and “decentralising” problem solving utilising cryptoeconomics, I,e allowing a collective hive of designers solve a problem through stigmergy, enabled via the common medium of smart contracts; smart contracts that record and act as the work medium of the collective (Dounas et al, ArchiDAO eCAADe). Another vector raised is modularity, the tokenisation of physical objects and the application of a stigmergic logic in the assembly, extending collective hive approaches from design to construction. Finally, the projects created raise relevant questions on the role of the metaverse not only as a parallel digital reality, but as a potential augmented digital social space that acts as a link between distant physical spaces and actors.

In order to classify and further analyse the aspects of blockchain and decentralisation that are addressed by every output of the architectural design studios, we have constructed seven thematic clusters. Each cluster corresponds to an identifiable way in which blockchain technologies and logic can be relevant to architecture. Most projects addressed more than one themes, and it is important to note that these themes were not imposed to the participants by the briefs, but they emerged as viable solutions to the briefs in different contexts, and were reinforced during the weekly design tutorials. The classifications, which will be further explained in the discussion section of the paper, are: Modularity, Stigmergic Assembly, Metaverse, CryptoEconomics, Collaborative Design/Fabrication, and Circular Economy.

3.2 Short project descriptions and classifications

A short description of select output from the studios follows. GreenCoin, Designing the city, Trustportation and CryptoHaus are titles that UoE students used to describe their projects.

GreenCoin, Fig.1, was a project that engaged with cryptoeconomics, modularity in terms of design, stigmeric assemply of the modules and physical/digital twins. GreenCoin as a token is an attempt incentivise participants to engage with green spaces and urban furniture maintenance, increasing the social trust on a city level and creating an ecosystem to spend the acquired tokens. It then engages with public event infrastructure, prototyping a module than can be bought and stored independently and then deployed in public spaces when large scale events ned pop-up spaces.

De-signing the city, Fig.4, engages with modularity, Cryptoeconomics, Collaborative design and digital twins. It begins with the hypothesis of a shift in terms of trust, according to which because of the rise of autonomous vehicles and digital maps, visual demarcations in cities will not be needed. They then develop an ecosystem of solutions to incentivise people to reclaim this freed up vertical real estate, as NFT exhibition spaces, transparent governance systems, or displays of any information that will be relevant to the different stakeholders. It then suggests autonomous living pods, placed, organised as DAOs, in the obsolete parking spaces, where people can stay by spending their acquired tokens for participating to the system.

Trustportation, Fig.2 & Fig.3, engages with modularity, stigmergic assembly, cryptoeconomics and collaborative design. It first recognises the need for mixed-use spaces adjacent with transportation nodes in big cities. After that, it suggests open-ended buildings, both in terms of architectural form and function, treating them as Decentralised Autonomous Organisations. Different stakeholders can vote to decide the program distribution within the building, which has non-fungible cores and structure and fungible temporary infill parts, than can get 3Dprinted and then recycled, based on the evolving needs of the building.

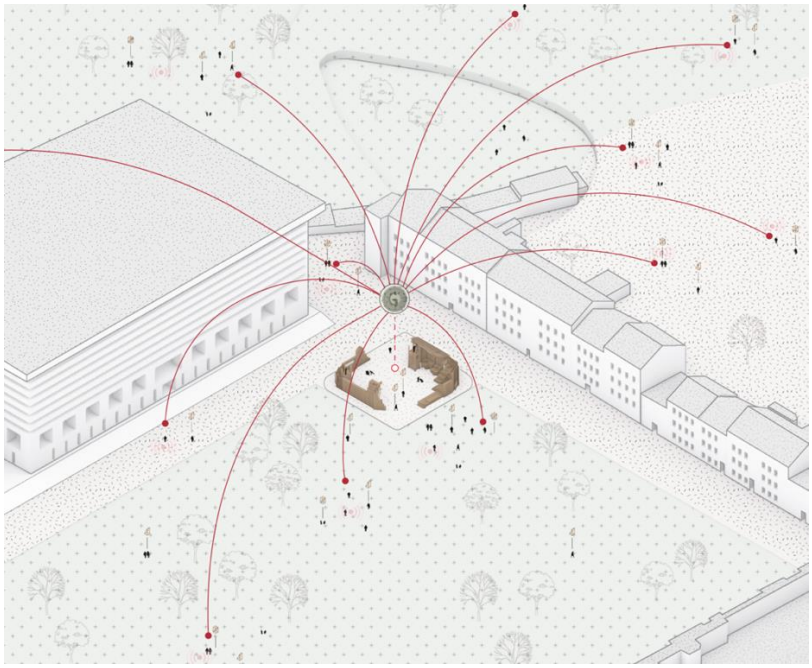


Figure 1. GreenCoin, modular structure, modules dispersed across the city, Source: UoE, diagram by Lucy Boyd, Sam Elliot, Yunan Wang 2022**.**

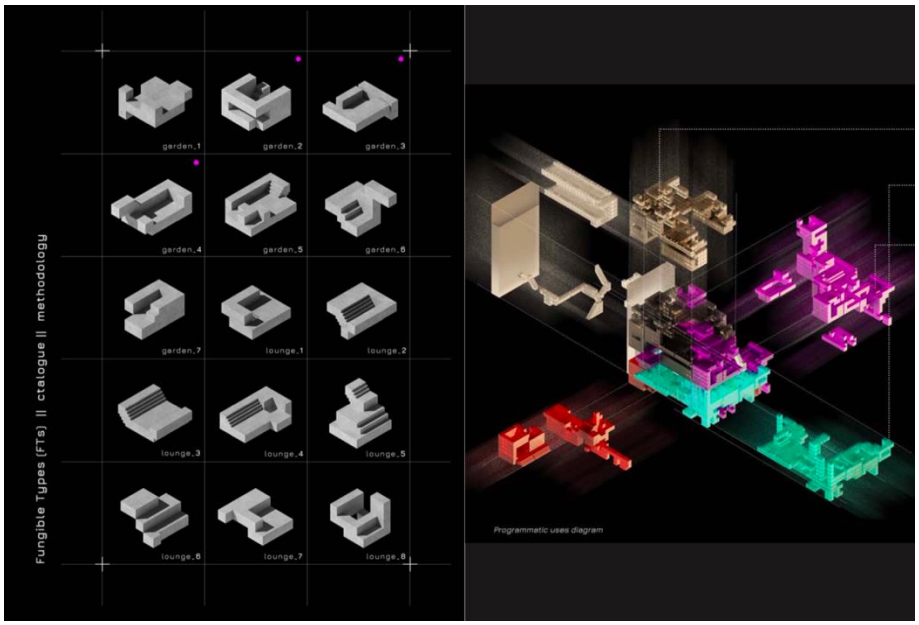


Figure 2. Trustportation, fungible parts and program distribution Source: UoE, visualization by Leo Chiu, Panagiota Mousa, Be Yang, 2022**.**

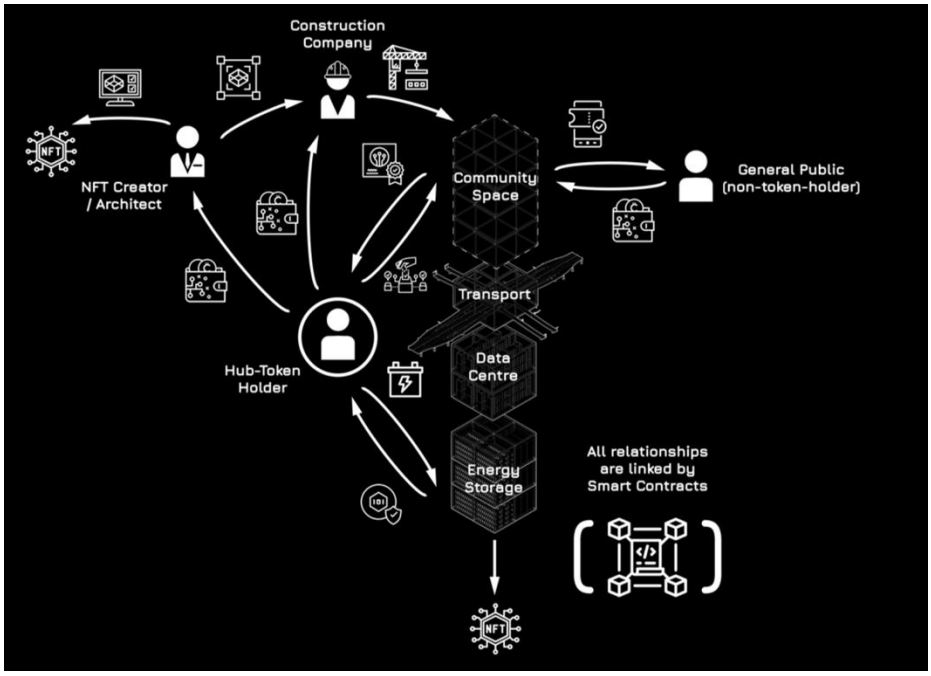


Figure 3. Trustportation, building as a DAO, Source: UoE, visualization by Leo Chiu, Panagiota Mousa, Be Yang, 2022**.**

CryptoHaus engages with cryptoeconomics, digital twins and mapping. It begins by identifying suitable areas with a lack of social housing of with housing infrastructure that needs updating. It then suggests a scheme in which the construction costs are offset in the whole lifespan of the building and the rent is equivalent to a fractional ownership of each apartment. The low rent becomes possible because the interests of all the stakeholders are aligned in a way that the initial investors, the tenants and the participants from the AEC industry get rewarded by the success of the building over time rather than a specific instance in the present.

In UoD, the brief had a focus on urbanism in terms of scale and level of investigation. Therefore, most of the projects revolved around mapping and incentivizing participants to help maintain accurate information for different uses. One project for example used a system to identify empty buildings in a city inspired by FOAM (FOAM provides the tools to enable a crowdsourced map and decentralised location services). The participants were rewarded to map and verify the location, condition, ownership status, and design of the buildings by taking pictures and scanning them. The complete database of empty building of different sizes, conditions and location could then be used for varying functions, based on the needs of the city over-time. Another project used a similar system to identify and rank green spaces, that could be used to deploy temporary housing solutions in case of natural disasters. Lastly, another project

focusing on urban farming created an ecosystem where participants were invited to identify potential areas that are appropriate for urban farming, and were rewarded for taking care of the crops, collect them and transport them to the distributed final selling points.

In the RGU and XJTLU workshop, the collective medical centre explored the idea of constructing a health system and its physical infrastructure including the buildings as a form of a common pool resources problem, where participants not only contribute through crypto-economics, but also participate in its governance through tokens. The project included a formulation of the design and construction of a medical centre through collective decision making.

In RGU, the collective factories for buildings project focused on a modular flying factory that could be assembled on demand in a particular area, create a factory for buildings, and then disassemble and fly to another location. The flying mechanisms and assembly were formed via an imaginative frame structure on air balloons. The whole system would operate with the logic of cryptoeconomics and digital twins where participants could either be a constructor operating a unit, or a community requesting the construction of a building. Apart from its imaginative infrastructure architecture idea the project was also innovative in turning a factory into a common pool resource problem that operates via cryptoeconomics.

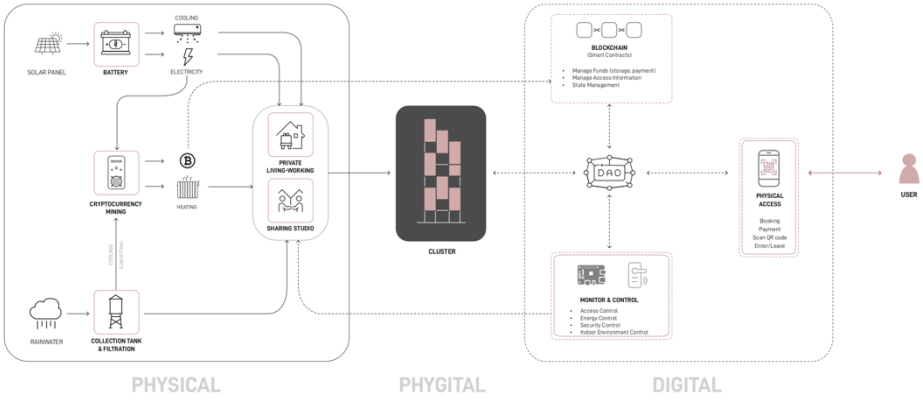


Figure 4. De-Signing the city, Building as a DAO, Source: UoE, diagram by Ice Chitmeesilp, Ciel Peng, Yolanda Wang, 2022

4 Discussion

After directly engaging with the attempts to constructively use the notion of blockchain for architectural design, we observed a series of current technical

and conceptual limitations that need to be addressed before the two fields produce viable prototypes. Firstly, in the technical domain, designers need scripting plug-ins, compatible with the already industry leading tools for computational design like Grasshopper, Dynamo, and Blender, to allow for linking the design process to smart contracts. Also, appropriate and useable smart contract templates that address the classifications that have emerged are needed, as well as their respective plug-ins for digital design tools. Furthermore, we need ways of communicating and saving transparently files from decentralised file storage systems like IPFS and Swarm. Finally, we need wallets natively embedded in CAAD applications, to handle private/public key infrastructure as current implementations are risky, exposing private keys in plain text.

As mentioned before, the classifications emerged as a result of the initial analysis of the responses to the briefs, and were not superimposed. However, the terms used to describe them, were chosen or synthesized by the authors, with some of them having different meanings in different contexts. Cryptoeconomics, which in short describe the incentivazation system that allow blockchain based finance to happen, were described in further detail earlier in the paper. Modularity refers to the design of structures that can be broken down to discrete parts. The Stigmergic Assembly refers to the collaborative assembly of structures, where the actors who participate on the process do not have knowledge or control over the final outcome. The Collaborative Design/Fabrication describes the situations where different actors are incentivised to participate in the design or production of parts of an artefact. Digital Twins, refer to the digital models of objects that approximate many characteristics beyond form. The Metaverse and Circular Economy are popular terms but lack all agreed definitions. In this context Metaverse is a digital, three-dimensional space for socialisation and Circular Economy is a model of production and consumption that encourages sharing and reusing.

Conceptually, cryptoeconomics, collaborative design and modularity were topics where architects seemed to excel and were able to synthesize creatively. However, we need to engage with projects that improve the understanding of the processes of circular economies, digital twins, and stigmergic assemblies; fabrication and production processes where the interests of multiple parties involved are aligned, the divisions between the various actors involved are blurred, and the co-ordination happens bottom up without centralised control.

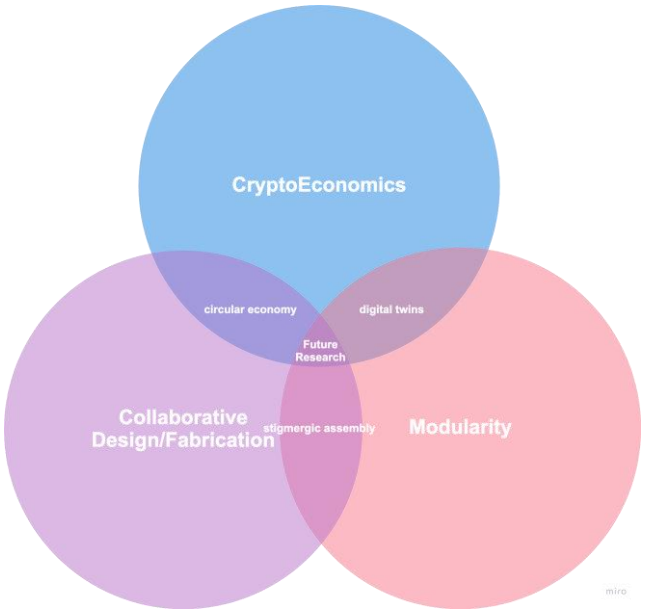
All the outputs from the four distinct academic design studios were evaluated, cross-referenced and graded against the seven emerging thematic clusters, with the grades ranging from zero to three based on their level of affinity (Table1.). After adding the grades from all the individual projects, the three highest graded themes were Cryptoeconomics (41), Modularity (32), and Collaborative Design/Fabrication (28). Analysing table 1, we constructed a Venn diagram, where we included the six most highly graded thematic clusters, creating overlaps based on thematic affinities that emerged after analysing the

projects. We believe that future research should be shaped by the emerging clusters and areas of focus.

Table 1. Classifications of different projects based on the thematic clusters

Studios	Modularity	Stigmergic Assembly	Metaverse	CryptoEconomics	Collaborative Design/Fabrication	Digital Twins/Mapping	Circular Economy
ESALA							
GreenCoin	3	3	0	2	0	1	1
TrustPortation	3	3	0	3	2	0	0
DeSigning the city	3	0	0	2	1	1	0
CryptoHaus Coop	0	0	0	3	0	1	1
ReciproCity	0	0	3	1	0	1	0
UoDundee							
Urban Farming	0	0	0	3	0	3	2
Resilient Athens	1	1	0	1	2	3	0
Universal Design (abandoned buildings)	2		0	2	3	3	0
XJTLU - MArch							
Brandless Architecture	3	3	1	1	1	0	2
Decentralised Augmented Space	2	1	1	3	3	2	1
Spontaneous Growth-Coastal Cities	3	3	0	2	2	1	1
RGU - MSc AAD							
East of Eden - Urban Planning	0	2	0	3	1	0	0
Hyperloop Station	1	1	0	1	2	2	1
Geodesic Portable Pods	3	1	0	1	3	0	2
Community Centre	3	1	2	3	2	0	3
Decentralised Community Centre	1	1	0	3	1	0	0
Sports Hall and communinty Centre	1	3	0	3	2	1	1
Smart Contract Community Centre	3	1	0	1	2	3	0
Health Centre	0	1	0	3	1	1	0

Table 2. Venn Diagram



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