21E8: COUPLING GENERATIVE ADVERSARIAL NEURAL NETWORKS (GANS) WITH BLOCKCHAIN APPLICATIONS IN BUILDING INFORMATION MODELLING (BIM) SYSTEMS

PROVIDES NG
[1] *UCL, Bartlett School of Architecture*
[1] *provides.ism@gmail.com*

Abstract. The ability of GANs to synthesize large sets of data is ideal for coupling with BIM to formulate a multi-access system that enables users to search and browse through a spectrum of articulated options, all personalised to design specificity - an 'Architecture Machine'. Nonetheless, due to challenges in proprietary incompatibility, BIM systems currently lack a secured yet transparent way of freely integrating with crowdsourced efforts. This research proposes to employ blockchain as a means to couple GANs and BIM, with e8 networking topology to facilitate communication and distribution. It consists of a literature review and a design research that proposes a tech stack design and UML (unified modeling language) use cases, and presents preliminary design results obtained using GANs and e8.

Keywords. 21e8; GANs; Blockchain; BIM; Architecture Machine.

1. INTRODUCTION

There has been an increasing amount of research in Generative Adverserial Networks (GANs) applications in architecture, mostly focused on generating floor plans to optimise building layouts or form-finding using techniques of StyleTransfer (Chaillou, 2019) (SCI-ARC, 2020). Besides creative production, GANs intelligence in handling 'large-scale problems, for they are too complex' and 'small-scale problems, for they are too particular and individual' has immense potential in relieving repetitive and bureaucratic processes for architects, including automating provision frameworks and the qualification of designs specific to local building regulations (Negroponte, 1970) (Coons, 1964).

Current research made significant contributions in generating new workflows, but they are generally scattered attempts that lack connectivity with one another, thus, may not necessarily be 'smart' - which requires dynamic networking - and may contribute to a trivial increase in productivity of the architectural industry (DOE, 2020) (McKinsey, 2017). Since much of GANs are open-source efforts, there needs to be ways in which such information can come together and freely integrate into app stacks - an 'Architecture Machine' that enables a multi-access system (Negroponte, 1970). Amalgamating readily available Information and Communication Technologies (ICTs) may assist inclusivity by directing micro-values back to individual actors who create/contribute contents.

PROJECTIONS, Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021, Volume 2, 111-120.

BIM and blockchains may provide prospective ICT solutions - the former helps with interfacing between a scattered chain of actors; the latter helps with anchoring transaction and payment data in an immutable manner to facilitate transparency in information exchanges (Ng, 2020a) (Satoshi, 2008). Blockchain-BIM coupling enables streaming data channels and peer-to-peer (p2p) financial incentives for quality input in a Common Data Environment (CDE). This can sustain value/cash flow for actors and assist the formation of 'agencies models', 'in which one player could simply accept the "agency" of another player ... (although each player only works for their individual interests) ... The action of acceptance would have the form of being entirely cooperative, as if "altruistic" ' (Nash, 2008). Nonetheless, this would demand strategies in networking, to which the e8 topology presents a prospective optimal in information communication (Lisi, 2007).

This paper aims at proposing an agencies model that efficiently divide payoffs amongst open-source efforts in softwares and workflows - to diversify the limited proprietary softwares and smart workflow options - so as to be inclusive to a broader range of architectural inputs in our CDEs.

2. Methodology

This paper consists of a literature review and a design research. First, it reviews the most recent literature in GANs, e8, blockchain, and BIM research, and identifies prospects in integration. Then, it proposes possible solutions on means to integrate using a tech stack design, explains methods for implementation using UML use cases that illustrate how such systems may function for a scattered chain of designers, contractors, and clients. Finally, it presents sets of initial results on how GANs and e8 topologies may help to automate repetitive processes in urban design specific to Transit-oriented Development (TOD) and incentive zoning.

3. Literature Review

3.1. GANS

This research experimented with two types of GANs - StyleTransfer and pix2pixHD. The former 'render the content of one image with the style of another'; the latter synthesises 'photo-realistic images from semantic label maps' (Xu, et al., 2018) (Wang, et al., 2018). The author tries to integrate both GANs to diversify combinatorial production pipelines.

The potentials of StyleTransfer in generating and qualifying 'a large and highly diverse quantity of floor plan designs ... (and) offer a proper classification methodology' have been tested by Chaillou (2019). He focused on building-scale organisations that optimise functional parameters (e.g. building footprint, program, circulation, orientation, etc.). This research takes it one step further - from the transfer of function-style to network-style, which may offer prospective applications beyond building to urban scale.

Wang (2018) trained his Pix2pixHD on the Cityscapes Dataset (2020) to facilitate 'interactive image manipulation' in urban images, where users can 'change (semantic) labels in the original label map to create new scenes, like replacing trees with buildings' and 'edit the appearance of individual objects in the scene, e.g. changing the color of a car or the texture of a road'. This research expands this to the manipulation of videos extracted from 3D city models, which can act as a near real-time visualisation engine that directly translates between 2D and 3D representations to relieve the intensive rendering works for designers.

3.2. 21 & E8

A multi-access system would demand strategies that increase network speed, facilitate search functions in CDEs, and anchor all transaction data to secure royalty and liability in participatory workflows.

This research proposes to employ 21e8 strategies. E8 - a mathematical solution for the kissing number problem - presents a highly symmetrical and densely packed lattice in sphere packing (Lisi, 2007). It can be employed as a network topology that encodes and decodes messages during information transfer with high efficiency, thus, presents immense potential in the application of blockchain. 21 million is the total block capacity that can be mined; thus, '21' represents network strategies in blockchain (e.g. halving) (Satoshi, 2008). '21e8' has been rapidly studied by blockchain communities; one of which is a startup - 21e8.com (2020) - that decentralises real-time content creation for web3.0, which has potential application in building a BIM system upon a distributed network of databases.

21e8 may help to 'enable software studios to contribute to multiple projects concurrently ... combine the benefits of both open source code and enterprise grade engineering and support' (Agencies, 2020). Crowdsourcing efforts would need the design of agencies models to assist the division of payoffs and diversify coalitions (e.g. crowdfunding, where agencies can be modelled mathematically using game theory to design protocols for incentive provisions) (Nash, 2008).

3.3. BLOCKCHAIN & BIM

Nakamoto (2018) proposed a p2p transaction system secured with timestamp functions - bitcoin. 'It aimed at improving the autonomy of information transactions within a decentralised network to eliminate the time and resources needed for institutional authentication' (Ng, 2020a). The backend to which is blockchain - a distributed ledger perfect to be coupled with BIM systems to tackle fragmentation, both on a technical and a socio-economic level - softwares and supply chain. Blockchain-BIM coupling may enable not only BIM softwares, but BIM systems by assisting consensus mechanism in design negotiation between multiple, competing parties to accomplish larger, more complex tasks that each party otherwise could not have achieved on their own. This facilitates cooperative or non-cooperative games that give emergence to harmonic outputs (Nash, 2008).

There are various blockchain-BIM initiatives; nonetheless, most of them are not aiming for BIM systems that facilitate agencies models, but rather, proprietary BIM softwares, which is an obstacle towards inclusivity and accessibility, especially for small-scale actors, for two main reasons. First, scalability, which is the speed capacity for a network to handle a growing amount of transactions (Ng, 2020a). Scalability issues within a decentralised network contribute to high operational costs and significant transaction fees at each exchange. If crowdsourced or low-cut versions are not available, the proprietary cost itself may make most blockchain-BIM products potentially unaffordable to most businesses.

Second, incentives, which can take forms of monetary or social values. Currently, there are limited ways to realise values in architectural designs beside developing physical buildings. If architectural information is essentially intellectual content - same as any other content we see on social media, why can influencers realise value from their content almost instantly but architects cannot? There has to be ways in which incentive provisions are designed into the decentralized network structure. One way is to build consensus mechanism on valuation of information objects in CDEs to enable network effects (e.g. collaborative filtering/rating). This is what search engines, like Google Page's (1999) Rank, are doing to index information and rank web pages according to their relative importance, where content values can be realised in terms of network effects. A blockchain system would take this one step further: instead of a proprietary ranking, users can have control over such ranking and directly vote on works they appreciate in CDEs.

Along these lines, building connectivity within architectural production demands the design of BIM systems that are inclusive to open-source efforts, efficient in directing micro-values to content creators/contributors, and incentivise value/cash/data flow by rewarding quality work. This also helps incorporating open-source AI to relieve repetitive/bureaucratic works and increase productivity.

4. Design Research

4.1. INTEGRATABLE APP STACK

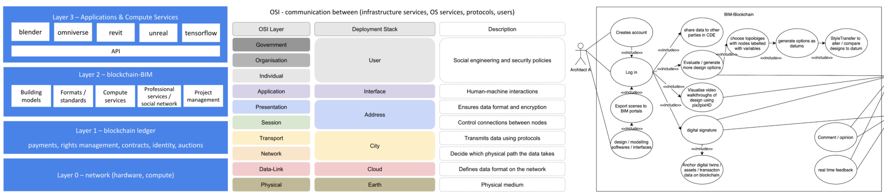

Figure 1. (a) The proposed tech stack. (b) The Proposed Open System Interconnection (OSI) model. (c) The proposed workflow. Source: author.

Blockchain's universal communication and control protocol can help the stacking of multiple applications and API (application programming interface) units into BIM software packages on demand; whereas its Shared Data Layer can help to anchor information assets to facilitate an immutable CDE and a means for BIM systems to incorporate crowdsourced efforts (Ng, 2020a). This has further applications in architecture, where decision-making and negotiation processes in design and contractual matters can be facilitated by an integratable app stack - we may begin to design a range of compatible interfaces as access portals for the specific needs of various users to enable real-time communication among a scattered chain of designers, contractors, clients, and, even, average citizens to diversify agencies models (e.g. crowdfund for collective housing) (Ng, 2020b).

GANs image-processing techniques can be incorporated as compute services that automate the generation of synthesized data. StyleTransfer can diversify available options based on users' different levels of design demands (e.g. clients can qualify design proposals by architects; amateur users can be empowered to deal with basic design works, etc.). Pix2pixHD can automate repetitive visualization works to provide designers with the autonomy of curation, and collapse the linearity between 2D to 3D translation. Together, the system and its users continuously create data that feed into itself via diverse value routes and streaming data channels, which can, in turn, be used for the training of AI (NChain, 2020). This forms a computer architecture that facilitates participatory production pipelines via crowdsourced services, which are built upon universal protocols.

4.2. UML USE CASE STUDY

Figure 1c demonstrates one possibility of workflow for urban design. First, architect A creates an account on the digital registry via BIM interface. A can choose to design with softwares that provide better creative control (e.g. Maya) and be visualized in BIM portals in real-time via APIs (e.g. Universal Scene Description) (Pixar, 2020). For design evaluation, A can use e8 topologies with nodes labelled with zoning parameters to generate a range of datum, which can be compared with A's designs to evaluate the deviation from the hypothesized optimal. A can then use StyleTransfer to automate alterations and generate more options; all articulated options can be shared to multiple parties simultaneously via CDE. Clients can download a low-poly version of the design/datum to save runtime and relieve network load, where surface subdivision and pix2pixHD visualization can be carried out at local desktop via simple interfaces at client-end BIM portals. Clients can directly label designs with comments, provide real-time feedback, and be distributed to involved parties. All information assets and transaction data are anchored on blockchain with each party's digital signature.

Within the stack, social media interfaces can be designed for architects to contribute micro-IPs (e.g. Minimal Viable Products, Proof-of-concepts, etc.) to build common asset models and collaborative designs. Micro-IPs can be traded at multiple stages of a project to crowdfund and collect users' opinions for future developments. The interface can be designed such that everytime a user posts, likes, comments, or forwards content, micro-values at the scale of a tenth of a cent/bitcoin/digital currency will be charged (Ng, 2020a). Users can also choose to pay with data or computational power. Subscription or other service models can be introduced for users who readily produce content. Percentage of the revenue can be shared among contributing/invested parties. Although the charge is minute, it may help to sustain high velocity value flows and prevent CDEs from populating with spam or low quality search results, because users are made aware that there is a realistic amount of cost to data input/processing/votes on information object, be it monetary or computational values.

This act as a means to decentralize information ranking within CDEs. Instead of a proprietary rank, users can vote on information objects via 'likes' to contribute their CPU/GPU power for mining or other computation-heavy tasks (e.g. AI training, rendering, etc.). This helps micro design challenges and information objects to progress into a physical architecture by competing, evolving, and surviving in a natural property market of architectural information (Ng, 2020a). When an IP is mature, it can be reverse auctioned to clients, who can easily analyse market options / cost benefits of the design and evaluate design quality / user-centric level via user rating/opinion, and benefit from the network effects already harnessed. Independent architects can take on a more proactive role within the supply chain, as opposed to waiting for design opportunities/client briefs, and sustain cash flows at early stages of design developments.

4.3. RESULTS - GANS

To further illustrate what the system can output in terms of architectural design, two on-going experiments on StyleTransfer and pix2pixHD are shown below.

4.3.1. StyleTransfer

This set of tests aims at reconfiguring urban topologies using GANs. One can infer the knowledge of 'types' using topology, which helps us to search for patterns in complex urban systems. Whereupon, we may begin to translate theoretical optimals in communication networks into urban topologies, and redistribute physical spaces accordingly.

This research experimented with e8 - a uniquely compact, simply connected lattice (Choe & Park, 2018). In spatial terms, this potentially implies a standard model to generate network optimals using different plane projections, and be used as a datum to analyse chaotic structures and qualify urban zoning. The e8 image below is a 2D representation of a 3D representation of a 4D projection of a 248D object (Madore, 2019). The high dimensional structure makes it technically difficult to operate on, but the ability of GANs to self-learn may help to open e8 opportunities for networking system and spatial configurations. Take TOD as an example, which aims at optimizing walking distance between public transport, residential, leisure, and business hubs. Each type of hub can be labeled as different types of nodes and be superimposed on e8 topologies to estimate the differences to the hypothesised optimal (Dittmar & Ohland, 2012).

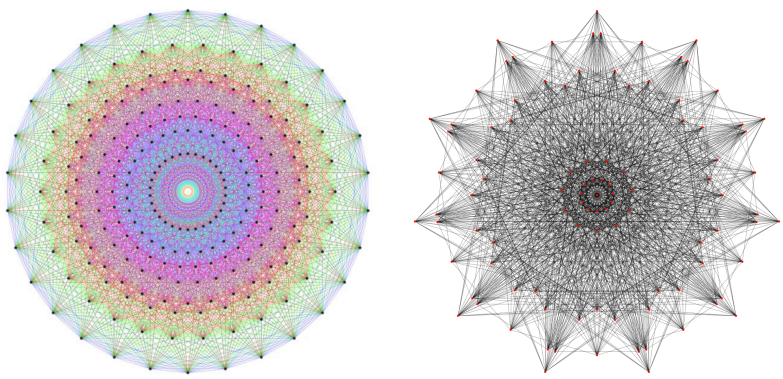

Figure 2. Representations of an e8 and a Leech Lattice (Lisi, 2007) (Madore, 2019).

Take incentive zoning as another example, which 'allows new development in certain areas to voluntarily achieve extra floor area by providing certain public benefits [...] contributes to infrastructure investments in growing neighborhoods' (Seattle.gov, 2018). This form of agencies model within urban developments can be assessed iteratively and adjusted periodically. For shorter time intervals, urban demands at different hours of the day can be sampled and evaluated using stochastic Markov models to predict changes in circulation, and formulate zoning provisions as a scheduler to incentivise private developments in facilitating different public benefits at different times of the day. For instance, incentivise malls to facilitate collective Taichi sessions or city forums during post-office hours. This would be especially helpful to highly compact cities like Hong Kong, where large-scale public areas are limited.

The following figures are two tests generated using StyleTransfer, e8, and Leech Lattice. The first test reconfigured the spatial planning of UCL using various projections of the Leech Lattice to distribute more communication channels between departments. The second test compared existing Hong Kong brownfield site topologies with e8 to deliver various recommendations on incentive zoning for revitalization. These sets of drawings remain as an artistic expression for now due to technical constraints, the next step to the project aims at developing high resolution outputs with enhanced precision.

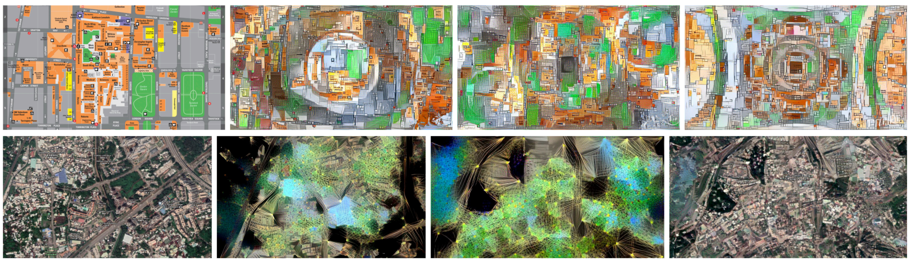

Figure 3. (a) UCL (2020) Bloomsbury Campus zoning plan and reconfigurations with Leech Lattice. (b) Current condition of Hung Shui Kiu Brownfields (scattered and fragmented sites with a highway segregating the urban fabric into two halves), reconfigurations with e8, and earth view visualization using StyleTransfer local urban texture maps. Source: author.

4.3.2. pix2pixHD

Project 'CAN-D' (City Adversarial Network Design) formulates a near real-time visualisation toolbox for architecture and urban design. CAN-D considers the participatory authorship problem, and aims at collapsing the linearity of pre- and post-production, also, human-machine design flow. Currently, the process of decision-making in design involves repetitive negotiation and contractual matters - a small change in a design triggers alterations in the entire digital model. Even if parametric tools are used to automate alterations, all visualisations would still have to be re-executed, causing repetitive work and low productivity.

There is an increasing amount of attempts on virtual desktops, which is especially challenging for real-time visualisation in a distributed system. For instance, blockchain-BIM decentralised computation is not very affordable outside central hubs due to scalability issues for the time being. It may work on a digital model with just a few megabytes, but BIM models easily reach over gigabytes. CAN-D tries to find alternative solutions by considering 2D-3D translation problem, which is fundamental not only to computational runtime, but also to architecture since the time of Brunelleschi. CAN-D takes a Gestalt approach - a perceptual grouping problem - which is perfect to be coupled with machine vision.

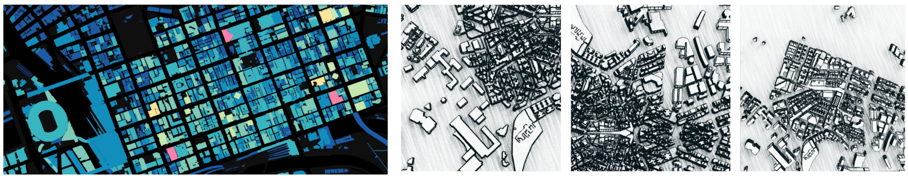

Figure 4. (a) A figure-ground drawing acquired from open-source mapbox. (b) Generated urban grids using procedural processing. Source: author.

Starting with a figure-ground drawing, which defines the boundary between spaces that can be acquired from any open-source mapbox, with color labels indicating the differences in building heights, embedding 3D information in a 2D drawing. CAN-D took a small portion of the city and utilised a rule-based procedural processing on mesh tension analysis to generate a range of new city grids, each has small articulated differences based on parameters. It helps to identify areas that are too segregated or densely packed with high rises, and provide options with better ventilation and circulation strategies. This step can also be done using StyleTransfer to estimate between the original functional zoning and a more organic arrangement, but for the aim of this project, CAN-D chose the cheapest compute combination possible.

Figure 5. Screenshots taken from video demo, access: https://dai.ly/x7r2qm3. Source: author.

After design generation comes visualisation, CAN-D asked, how to visualise all options in near real-time so to efficiently communicate the designs? The drawings already have building height data embedded, which can be easily extruded using modeling softwares, to which zbrush was used. The digital model is then semantic-labelled for machine vision (requires some manual power). CAN-D flew a virtual camera around this city model and feed the video walkthrough into a pix2pixHD, which was trained on german city dataset, and outputs a texture mapping visualization.

This demo is computationally affordable - compressing what would take days of work into just hours with a fully trained neural net. The output resolution is low, but this can be leveraged between costs, availability, and quality for the needs and capacity of different design works and phases. For the next step, CAN-D is expanding to a city-scale semantic labeling with personalized datasets, which may classify objects like wind corridors, infrastructural provisions, and zoning types to perform visualisation for a broader range of design needs. CAN-D is also testing out integrating other open-source AI into the pipeline, like GANbreeder for static visuals to achieve greater speed and flexibility.

Figure 6. (a) The next step of CAN-D is city-scale semantic labelling. (b) Ongoing experiments using GANbreeder - an open-source algorithm using evolutionary dynamics. Source: author.

Imagine the compute/communication time that can be saved just from efficient collaborative methods enabled by an integratable app stack that encompasses StyleTransfer, pix2pixHD, GANbreeder, and many more; such an 'Architecture Machine' can be made available by a blockchain-BIM system that standardize protocols to include a growing amount of open-source efforts.

5. Conclusion

This research considered how readily available ICTs - blockchain and BIM - can be amalgamated as a coherent system that are inclusive to crowdsourced efforts, especially AI Image processing GANs, and act as a socio-economic drive to changes in architectural production and the democratisation of AI. This research argued that the formulation of such forms of multi-access systems should put emphasis on topologies to relieve network load in synchronising and distributing information and logistics, and gave examples of how e8 can be employed on both a software and a design level. This research proposed tech stacks, OSI models, and UML use cases to describe how various actors - architects, clients, general users - can interact with the proposed system, and showed sets of initial design results generated using StyleTransfer and pix2pixHD. This research also illustrated how these algorithms can be coupled with local building provisions, such as TOD and incentive zoning, to automate and relieve repetitive and bureaucratic processes for designers - an 'Architecture Machine' (Negroponte, 1970).

The experiments were merely starting points that narrowed down to specific problems in architectural design. The production pipelines proposed will have to be actively tested to see how units of system components and compute services can give rise to a broader range of combinatorial strategies. It is hoped that more system designs would be inspired to assist architects in comprehending across physical and disciplinary domains and promote information transfer. Two important components to be further considered is the design of interfaces that provide navigational strategies within CDEs, and means to direct information to those who will potentially need it (e.g. interdisciplinary personalisation).

References

21e8.com, 2.: 2020, “21e8™” . Available from <https://21e8.com/>.

Agencies, A.: 2020, “Agencies.” . Available from <https://agencies.network/>.

Bratton, B.H.: 2016, *The Stack - On Software and Sovereignty*, MIT Press, Massachusetts.

Chaillou, S.: 2019, AI + Architecture | Towards a New Approach, *Harvard University*, **188**.

Choe, D.H. and Park, K.: 2018, On intersection forms of definite 4-manifolds bounded by a rational homology 3-sphere, *Topology and its Applications*, **238**, 59-75.

Coons, S.A.: 1964, An Outline of the Requirements for a Computer-Aided Design System, *Proceedings of the May 21-23, 1963, spring joint computer conference (pp. 299-304).*.

Cityscapes Dataset, C.D.: 2020, The Cityscapes Dataset, *Retrieved November*, **24**, 2020.

Dittmar, H. and Ohland, G.: 2012, *Transit-oriented development*, Island Press.

DOE, D.O.E.: 2020, “US Department of Energy: SMART Mobility Modeling Workflow” . Available from <https://www.energy.gov>.

Imperva, I.: 2020, What is OSI Model: 7 Layers Explained: Imperva, *Retrieved November 25, 2020,*, **from https://www.imperva.com/learn/application-security/osi-model/**.

Kumar, N.(: 2020, January 01), *Truths about OSI layers (Simple Method).*.

Li, Y. and et, a.l.: 2018, A closed-form solution to photorealistic image stylization, *Proceedings of the European Conference on Computer Vision (ECCV*, 453-468.

Lisi, A.G.: 2007, An exceptionally simple theory of everything. arXiv, *no title given*.

Madore, D.: 2019, The Higman-Sims graph, *http://www.madore.org*.

McKinsey, M.: 2017, *A ROUTE TO HIGHER PRODUCTIVITY*, McKinsey Global Institute.

Nash, J.: 2008, The agencies method for modeling coalitions, *International Game Theory Review*.

nChain, B.S.V.: 2020, The Meta-Verse. Retrieved August 24, 2020, from, *no source given*.

N. Negroponte (ed.): 1970, *The architecture machine*, Cambridge (Mass.): M.I.T. Press.

Ng, P.: 2020a, Disrupting The Information Economy of Architecture With Satoshi’s Vision - How can blockchain applications in BIM help to support a circular economy inclusive to local independent and small-scale actors?, *DC I/O*, **10**, 47330.

Ng, P.: 2020b, *Applying Satoshi’s Vision to Brownfield Sites Revitalisation in Hong Kong*, International Forum on Urbanism [IFoU].

Page, L., Brin, S., Motwani, R. and Winograd, T.: 1999, *The PageRank citation ranking: Bringing order to the web*, Stanford InfoLab.

Pixar, P.: 2020, “Introduction to USD. Retrieved November 24, 2020, from” . Available from < https://graphics.pixar.com/usd/docs/index.html>.

Satoshi, N.: 2008, *Bitcoin: A Peer-to-Peer Electronic Cash System*.

SCI-ARC, S.-A.: 2020, “Cyborg Misprision 3 : AI Methodologies, SCI-Arc 2020” . Available from <https://www.subinjameel.com/ai-methodologies-studio-2020>.

Seattlegov, S.: 2018, “Incentive Zoning” . Available from <https://www.seattle.gov>.

UCL, U.C.L.: 2020, “UCL” . Available from <https://www.ucl.ac.uk/maps/downloads/>.

Wang, T.C. and et, a.l.: 2018, High-resolution image synthesis and semantic manipulation with conditional gans, *Proceedings of the IEEE conference on computer vision*, 8798-8807.

Xu, Z.: 2018, Learning from multi-domain artistic images for arbitrary style transfer., *arxiv*.