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Incentivising Multidisciplinary Teams with New Methods of Procurement using BIM + Blockchain

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Incentivising Multidisciplinary Teams with new methods of Procurement using BIM + Blockchain.

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Abstract– This paper researches a potential method of incentivising AEC industry professionals to design to better than NZEB standards. Analysing the potential of a purposefully designed local microgrid storing excess energy generated by solar technologies embedded within the building envelope; the microgrid excess output is measured and recorded using a (Post Occupancy) "Blockchain" application and measured against the data provided at design stage on a (Predictive) "Blockchain" database. This paper researches how energy output predictions at design stage, by multidisciplinary teams, may be enhanced by BIM + Blockchain Technology. The paper researches the potential of a digital twin (predictive versus post occupancy) in pursuit of answering this question: "If a building can produce more energy than it is consuming, is there an opportunity for the building owner and/or design team/building occupants to sell the surplus energy as a commodity?" In turn, this creates the potential for "Added Value Networks". The first being a financial incentive for designers to strive for the very best building performance, and the second, a financial incentive for building occupants to conserve energy leaving more energy for sale. This paper will test the predictive energy theory and report on data generated by virtual sensors in a BIM model recorded on a (Predictive) Blockchain. This will be the basis for comparing predictive energy use against actual energy output. Actual energy output during occupancy can be recorded using real time sensors matching the number and location of the digital sensors. The information on both databases are secured using the immutable and transparent properties of Blockchain. This can provide confidence for transactions, securing the "Added Value Network".

Keywords– BIM, Blockchain, Microgrid, Sensors, NZEB, POE.

I Introduction

In 2018, at a conference in Canada; Lampros Stougiannos posed the question:

> "*Should the construction contract be changed"* [1]?

The question was posed after highlighting the disparity between technological advances and the construction contract. On one hand, modern technology has advanced immensely over the last twenty years. On the other hand, construction procurement methods used over a century ago stubbornly persist. This paper researches how construction procurement may develop in the future. Provided the Architectural, Engineering and Construction (AEC) industry is ready to adopt new methods. If new methods are to be realised in the future, they will have to adhere to new building standards. Currently, governments are aiming to introduce Net Zero Energy Building (NZEB) standards in the future [2]. NZEB standards are followed when producing a building that is capable of meeting its own energy demand through renewable sources [3]. By signing the Net Zero

Carbon Buildings Declaration, some parts of the world such as London, Los Angeles, New York, Paris, Sydney, Tokyo, and Toronto have all pledged to ensure buildings in their cities, new and old, will meet the net-zero carbon standards by the year 2050 [2]. The current culture of construction is very different to this future aspiration. Construction today is fragmented and defensive, participants prepare for battle rather than harmonious collaboration and do not strive to produce buildings that produce more energy than they consume. There is usually a lack of trust and a lack of information between the various parties. This, more often than not, leads to disputes [4]. AEC industry contracts today focus on pushing the risk to either the designer or the contractor and are hampered with excessive bureaucracy. This leaves people in quite a defensive mode throughout the contract; also adding to the tension is the relentless focus on the lowest-cost tender awarding which has numerous repercussions on build quality.

> *"You can pinch a bit here or there in the capital cost, but the outcome of that can result in far-greater costs in the performance of the building.-You are adding to the cost rather than getting to the optimum solution."* [5]

In all likelihood the construction contract will change in order to embrace new methods of procurement in the future [6]. The research in this paper proposes an initial step forward in this direction.

For buildings to be declared self-sustaining it requires a lot of analytical data to be sure that the claim is genuine. Sensors, microgrids, smart meters, and Blockchain technology allows this analysis to be possible. In 2016 the company LO3 Energy, created a real world use-case. It is called 'The Brooklyn Microgrid'. Using a network of community owned solar panels, members of the community in Brooklyn, New York were able to generate and store energy, then sell the excess energy to the neighbours in their community [7]. Microgrids that combine the capabilities of solar panels, smart meters and Blockchain technology have the power to bring small communities together and to turn large building projects into self-sustaining ecosystems [8].

The aim of this research is to explore and answer the question: "If a building can produce more energy than it is consuming, is there an opportunity for the building owner and/or design team / building occupants to sell the surplus energy as a commodity?" To answer this, the author addressed four main objectives.

- Critically appraise existing research on Blockchain technology and similar areas of collaboration and reward
- Hypothesise a solution with the capacity to incentivise clients, multidisciplinary teams and building occupants.
- Progress the hypothesis from theory to tested theory, conducting rigorous test.
- Analyse and report on the findings, discussing future potential.

The process of completing these four objectives is presented in this paper in the following sections. Objective one is carried out in section II (Literature Review). Objective two is presented in section III-b. Objective three is demonstrated throughout the entirety of section IV. Finally, objective four is reported in section V and VI of this paper. Beginning with the literature review:

II Literature Review

This literature review will cover the subject areas of BIM, Blockchain, Smart Contracts, Internet of Things, Digital Twins, Microgrids and Post Occupancy Evaluation. For the purpose of gaining a thorough understanding the author has read extensively in these areas, which are pertinent to the research. This chapter provides an overview of the current state of the art. These findings were sourced from academic papers, industry standards, guidelines, recent publications, and podcasts related to the research topic.

a) Blockchain

Blockchain technology, although not named as such at the time, was presented to the world in a whitepaper of 2008 called *"Bitcoin: A Peer-to-Peer Electronic Cash System"*[9]. Blockchain is the technology behind Bitcoin which has since been referred to as *"one of the greatest inventions in human history"* [10] and *"The technology that could transform how the entire economy works"* [11]. It has been more than ten years since the inception of Blockchain and the technology is still referred to as new. This is due to slow adoption across multiple industries. Blockchain slowly continues to push the boundaries of what many professionals once thought impossible [12].

The basic workings of a Blockchain: Timestamped transactions that are hashed together into an ongoing chain of hash-based proof-of-work [9]. That aside; a more modest definition for Blockchain, in its simplest form: A ledger of digital transactions; distributed across a network of computers. Importantly instead of being controlled by one company or individual it is shared among all individuals willing to partake on the network.

This simple but powerful attribute of participation consensus renders the technology extremely difficult to tamper with; as to do so would result in an obvious deviation from the agreed rules set by all remaining people on the network. It is this very notion of participation consensus that is of particular interest to the AEC industry, since it enables trust. This attribute allows for many incredible use-cases, which simply were not possible prior to the invention of Blockchain technology. These new use-cases have the potential to transform the AEC industry in many ways [10]. The unknown boundaries and limitations of Blockchain technology today are comparable to the once unknown boundaries and limitations of the internet prior to widespread adoption. Blockchain adoption is still in its infancy but there are promising innovations in development.

> *"In the same way that the internet changed information services forever, Blockchain will transform services of value forever. The only question is: What form will this transformation take?"* [13].

Early adoption of Blockchain technology is underway; Blockcharge, a Blockchain based peer to peer Energy Company is working on charging, authentication and payment systems for people who own electrically powered vehicles. The aim is to make the distribution of energy available where it is needed most. Blockcharge predicts, that in the future, charging stations for electric vehicles will be located outside frequently visited buildings such as offices, shopping malls and health clubs [14]. This proves Blockchain is applicable to another industry, not only the AEC industry. It may eventually be the glue that binds other industries to the AEC industry. Podcasts are devoted to this topic. During one such podcast, the discussion explored the idea of Blockchain technology merging the AEC industry with the automotive industry. Over performing buildings, that produce more energy than they consume, may one day sell the excess energy to electric car owners; turning the eco-friendly buildings into renewable energy power plants, that charge electric vehicles [15]. This Blockchain use-case would execute "Smart Contracts" between the energy provider and energy consumer, from peer to peer.

b) Smart Contracts

Blockchain has the ability to execute contracts. These contracts are known as Smart Contracts. The execution of a smart contract is made possible without the need for a trusted third party intermediary by replacing them with a digital handshake directly from peer to peer [16]. Smart contracts are self-executing contracts, which are trigger when pre-defined conditions are met. The pre-defined conditions can be embedded into the Blockchain to execute autonomously [17].

Smart contracts were invented along with the invention of the Ethereum platform. Ethereum, similar to Bitcoin, is a cryptographic currency. Differently though, Ethereum is specifically designed as a platform for applications to be built on. These applications can be programed to execute smart contacts. The smart contracts on each application can be programed differently, on a project to project bases, to meet the needs of each different use-case [18]. The potential of Ethereum is fully unlocked when it is paired with the power of the Internet of Things [19].

c) Internet of Things

The Internet of Things (IoT) is the networking of everyday objects connected to the internet. The IoT allows inanimate objects to act autonomously. The IoT is considered an ecosystem that contains integrated smart objects equipped with sensors that network, unify and process technologies together, resulting in an environment where smart services are continuously automated and delivered to the end user [20]. The IoT is a surveillance network which monitors people and places. The potential for untrustworthy miss-use is of huge concern. Therefore, the IoT can only be a positive advance in modern technology when trust is ingrained into the fabric of the connected devices [21]. Blockchain technology relies on consensus; it is therefore the only technology to ever make "trust" a reliable reality on the internet [22]. The growing agreement among technology companies is that, Blockchain is essential to unlocking the full potential of the IoT [13].

One potential IoT application was identified by a focus group in the city of Melbourne. It was noted that buildings and structures could be equipped with smart sensors connected to the internet, allowing for structural fatigue monitoring and pre-empting maintenance work [23]. The IoT applied to the built environment is particularly impressive when combined with the power of a Digital Twin [24].

d) Digital Twin

A Digital twin is a virtual replica of a physical object, building, or structure. To enable the full potential of digital twins a pre-existing requisite is the IoT. An existing example of a successful Digital Twin: A windmill was modelled digitally in 3D to match its physical counterpart identically. The real-world windmill is equipped with sensors that report back data displayed to the end user via a 3D virtual model. This allows for predictive maintenance to be identified. Real world examples of digital twins range from wind parks to power plants, the digital twin enables continuous surveillance [24].

> *"The convergence of four major solutions — the circularity model, the product environment (BIM), the smart sensor (IoT) and the trust model (blockchain) — could directly communicate and form a digital twin"* [25].

Digital twin development is the beginning of the infrastructure that ties BIM, cloud platform technologies, and the IoT together. This has the potential to provide truly smart and connected cities.

The growth of the IoT and Digital Twin technology will result in more data being sent to cloud services. This growth will potentially result in the ability for AEC professionals to produce a true information model; where everyone and everything feeds into one federated database. The future ability to take and process real-time data from built assets will impact the future environment. This will inform design changes throughout the operational phase of built assets [26]. A study carried out by J. Chen, T. Bulbul, J. E. Taylor, and G. Olgun provided a proof of concept. Embedding real time data into a BIM model and making that BIM model dynamic by using modelled components that updated when receiving new data from real world sensors. The researchers verified that real time data was successfully imported into the BIM model and visualized clearly via the BIM model [27]. The aggregation of real-time data post build completion will open up new opportunities to analyse Post Occupancy Evaluation (POE) in new ways.

e) POE

POE is the study of a buildings performance during the operational phase; an analytical comparison of the building performance versus a set Key Performance Indicator (KPI) when in-use [28].

> *"Despite the effort that goes into design, architects often remain - sometimes willingly - in the dark about how their buildings serve their occupants. Increasingly, data driven clients want to verify the design goals of their completed projects"* [29].

To achieve this, the relatively new concept of digital twin technology is slowly being implemented into the process of POE. Software applications that enable digital twin POE are: Data Acquisition Technology (DAT) and Project Dasher by Autodesk. DAT has already been integrated with Onuma Planning Systems (a BIM tool) whereas Project Dasher is still in development [30].

One specific POE report researched eighteen buildings. The report noted that all eighteen buildings in question underperformed when compared to their design stage predicted performance [31], this is not uncommon. The following graph was taken from that paper, reporting on the findings.

Fig. 1: Predicted analysis versus in-use data [31]

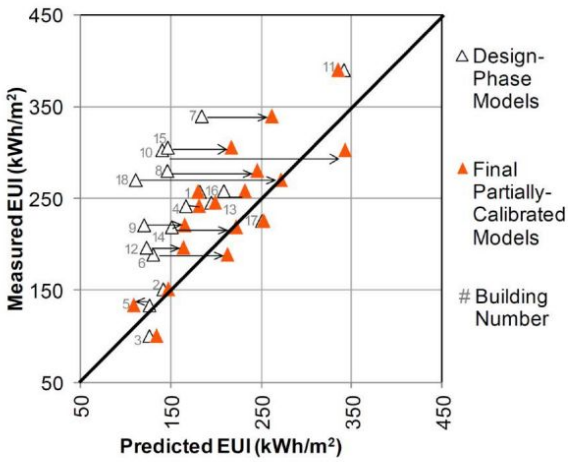

Figure 1 illustrates how all eighteen builds differed in their energy performance when compared to their respective KPI, the designed intention. This highlights a gap between predicted energy performance and the actual energy performance [31]. The evaluation of building performance and occupant satisfaction in the post-occupancy phase is relatively under-developed compared to evaluation methods applied during a buildings design phase [32].

f) Microgrid

A microgrid can be described as a cluster of loads. Loads are Decentralized Energy Resources (DER) (e.g. PV panels) and Energy Storage Systems (ESS) (e.g. battery), which operate in conjunction to supply electricity reliably. Microgrids can be in four conditions:

- Grid-connected
- Decoupling
- Island-mode
- Recoupling

If a microgrid exchanges power with the main distribution grid, it operates in grid-connected mode. In the islanding condition power is exchanged only locally between loads. Decoupling and recoupling is the process of un-connecting from the main distribution grid and reconnecting to the main distribution grid, respectively. Microgrids are seen as an approach to reduce centralized power distribution by sourcing and sharing renewable energy locally between individuals in a community [8]. There are real world use-cases, for example, the previously mentioned L03 Energy Brooklyn Microgrid noted in the introduction.

g) BIM

Essentially, BIM is a process. A digital form of construction documentation; the process is a marriage of technology and digital information. BIM radically improves client outcomes and asset operations. Moreover, BIM is a strategic enabler for improving decision making for both buildings and civil engineering infrastructure, throughout the entire lifecycle of a project [33]. The BIM process is enabled by BIM software, of which there are many. Examples being: Autodesk BIM 360, Autodesk Revit®, Navisworks, Archicad, Dynamo, and Solibri. These BIM Software applications are currently being used globally. The BIM process has become mandatory on projects that fit certain criteria. Parts of the world such as Sweden, Finland, Russia, Denmark, Korea, Hong Kong, Dubai, Australia, Singapore, and the UK have all mandated the BIM process to varying degrees [34].

BIM level 2 is the current standard for the previously mentioned countries. The next step is BIM Level 3. BIM level 2 is the sharing of object based models and data between two or more disciplines. BIM level 3, on the other hand, aims to have multiple disciplines feeding into one federated database [35]. The levels of BIM will continue to rise as further technological advances progress. Mandating BIM level 2 is the first step towards a world where eventually, BIM Level 3 is the entry level standard [36]. All levels of BIM require a medium of exchange and this medium is referred to as a Common Data Environment (CDE). The CDE is the agreed source of information for any given BIM project, used to collect, monitor, maintain and manage the documentation process [37].

h) Autodesk Revit®

Autodesk, a software application company, provides the most popular BIM software applications to AEC industry professionals. Autodesk Revit®, being one of their services is the most widely used application [38]. Autodesk Revit®, being a market leading application is recognised by Technological University Dublin, and for this reason, was the chosen medium for analysis throughout the research in this paper.

Autodesk Revit® is a multidisciplinary BIM software. Users model building projects from default or customised templates. The users populate these projects with families. Families are parametric, data rich 3D objects. Families are defined by their category, for example, doors are listed as doors and windows listed as windows. The category of an object is useful to be aware of when using Dynamo.

i) Visual Programming – Dynamo

Dynamo once was an optional add-in to be used alongside Autodesk Revit®. It now comes packaged into Autodesk Revit® as default, due to its popularity within the user community. Dynamo is a visual programming tool. The interface is user friendly and the learning curve is relatively modest; making the tool accessible to users without a programming background.

> *"Dynamo is, quite literally, what you make it. Working with Dynamo may include using the application, either in connection with other Autodesk software or not, engaging a Visual Programming process, or participating in a broad community of users and contributors" [39].*

III Methodology

The author has investigated various methodologies and chosen Design Science Research (DSR). DSR is a method of evaluating innovative IT solutions that extend the boundaries of known applications. The core mission of DSR is to develop knowledge that can be understood by professionals and applied in practice [40]. DSR is a systematic form of designing a solution that involves the development and study of "artefacts" [41]. The "artefact" can be a concept developed on an existing platform and used to create new functionalities. The author chose DSR because it applies to researchers who wish to present innovative BIM solutions, evaluating them for real world use-cases. [42]. The "artefact" in this paper is a BIM model equipped with a Blockchain.

Figure 2 illustrates the framework of DSR. Five distinct process steps are outlined; (a) Awareness of problem; (b) Suggesting a solution; (c) developing the solution; (d) implementing the solution and evaluating the process; and (e) specifying learning outcomes. Each of these steps apply to the research in this paper.

The first objective of this research was to implement a literature review. The second objective was to hypothesise a solution with the capacity to incentivise clients, multidisciplinary teams and building occupants in a BIM setting; these two objectives followed the first two process steps of DSR. The third objective of this research was to progress the hypothesis from theory to tested theory, conducting rigorous test. The fourth objective was to analyse and report on the findings, discussing future potential. These last two objectives adopt process steps three, four and five of DSR. Process steps three, four and five consisted of quantitative approaches; developing the proposed Blockchain use-case. Examining, testing, re-examining and re-testing until all variables become exhausted, unveiling the pros and cons of the application.

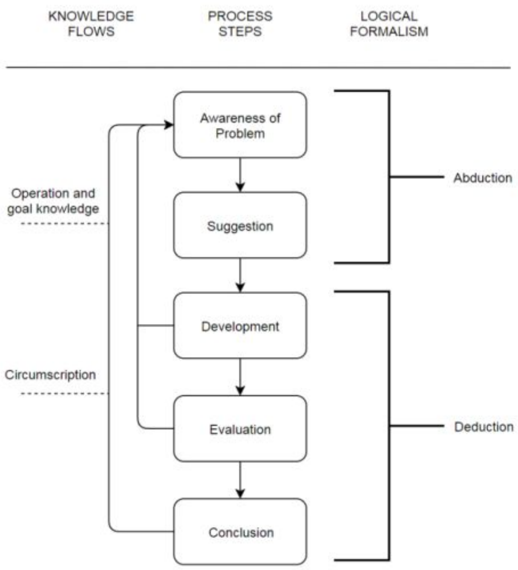

Fig. SEQ Figure * ARABIC 2: DSR process steps, drawn by author.

a) Awareness of Problem

The initial step of DSR is to note the issue by diagnosing the research problem [43]: Currently to be awarded a tender contract, bidders are incentivised to lower their bids in order to win the contract. This results in a race to source cheap materials in order to keep profit margins high for the builder. Unfortunately, this leads to inefficient building performance and a loss in potential prosperity which could have been achieved. Addressing the gap between expected performances versus actual performance is imperative [44]. Dr James Harty suggests an example; a sub-contractor offers to fit a solar panel for a fixed sum before a competitor undercuts that bid with a cheaper and less efficient product. The contract is usually awarded to the lower price. However, if the more expensive solar panel performed better over twenty years with less maintenance and more energy conversion while remaining aesthetically pleasing; should there not be a method to reward that effort? Harty goes on, attributing Blockchain as one possible method of remedy [45].

b) Suggesting a solution (Blockchain)

Constructing an "artefact" in DSR demonstrates that the process can be adopted by industry professionals. It enables a change in current work practices [46]. As explained in the Literature Review: Blockchain Technology has potential for application in the AEC industry, the suggested solution put forward by the author in this research is Blockchain Technology. Applying the "artefact" in a BIM setting is demonstrated in full throughout section IV-d.

c) Developing the said solution (Dynamo)

For the solution to be relevant from an academic perspective, the process of developing the artefact must be transparent. This requires an explanation of the development process and the decisions that were made as the artefact evolved. The development process is illustrated in detail on the authors ePortfolio website.

d) Implementing the solution and evaluating the process

The implementation of Blockchain technology in a BIM setting: The following section, section IV, Research Testing covers this in great detail.

e) Specifying learning outcomes

The final process step of DSR, specifying the learning outcomes involved self-interpretation and analytical reflection. This final process step of DSR is covered in sections V and VI.

f) GDPR

"The EU General Data Protection Regulation (GDPR), along with the new UK Data Protection Act 2018, will govern the processing (holding or using) of personal data in Ireland" [47].

To comply with GDPR the author has taken security measures to prevent the miss-use of information gained throughout this research. Lastpass, a password manager application was used to generate secure and randomised password codes for cloud storage access, where information was held in an organised manner. Two-factor authentication was also implemented to gain access to cloud storage. To achieve this, a hardware authenticator called Yubikey 5 was used. The final precaution taken to minimise data risk was to ensure only fictional designs were used when modelling in BIM software applications. This ensured no individually identifiable building design was displayed in screenshots illustrated throughout this paper; Allowing for the following open and candid discussion.

IV Research Testing

a) Scope

It is noted in the Literature review section II-d: Existing research has proven real-world sensors can populate BIM models with real-time information. With this in mind, the author expands on the premise of Digital Twin technology; taking the existing research a step further with Blockchain technology. Using the existing research as a base line the following basic conditions, for the purpose of this research, are assumed. Testing conditions:

- One floor, four walls and no roof.
- A heat sensor on the internal face of each wall receives data from a hypothetical real-world, geometrically identical, building.
- Each 3D virtual sensors in the BIM model displays a reading of 0.32 Kw

b) Building the Autodesk Revit® family

For testing purposes the author built an Autodesk Revit® family. The challenge was to create a 3D object family that could be placed on the face of a surface in a BIM model. To achieve this, a face-biased family template was used. Within the template the author proceeded to apply specific defining characteristics. For example, firstly, the family was categorised as a data device and secondly, the family was given a custom parameter named "Read from HTML". Screenshots of this information being added to the family can be seen in Figure 3 and 4 respectively below.

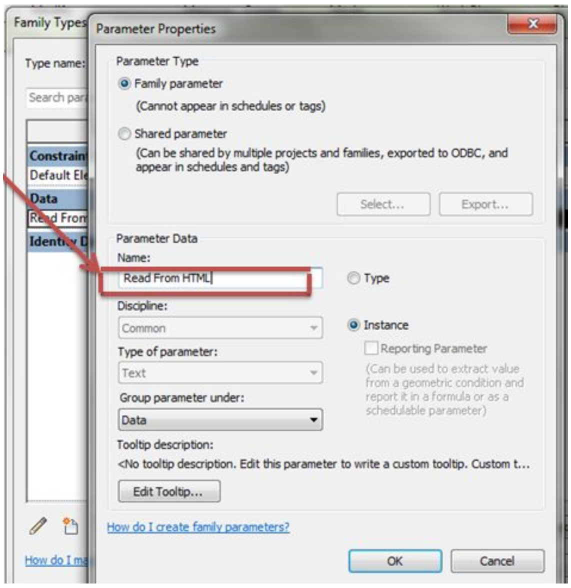

Fig. 3: Custom parameter prosperities added to the family to enable energy readings to be fed into the family data.

This family was then saved as a Sensor Family and loaded into an Autodesk Revit® project to be placed on a surface.

c) Building the Autodesk Revit® model

It is noted that the author is an Autodesk certified professional Revit® user. The process of building the model was in line with BIM Level 2 standards. The CIC BIM protocol was followed and when naming the file, the PAS-1192 naming convention was applied. (See Figure 4)

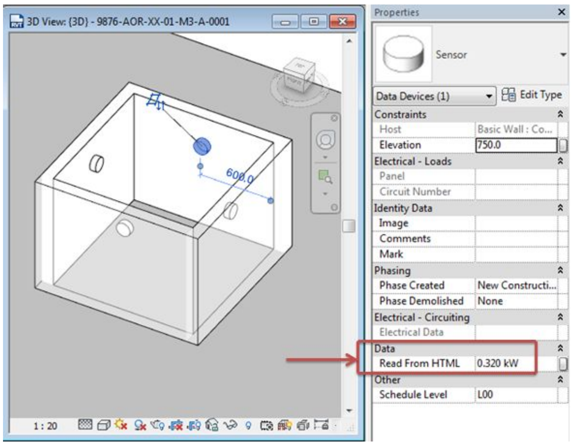

Fig. SEQ Figure * ARABIC 4: Screenshot of BIM model during testing. Source: Author.

In Figure 4 one of the four sensors is selected. It is clear that the data parameter displays an energy reading of 0.320 kW. To record this information from the model on a Blockchain database, the application Dynamo was used.

d) Building the Dynamo script

Figure 5 on the following page, illustrates the Dynamo script in its entirety. The script was broken down into three distinct phases, reflected in three varying colours seen in Figure 5. These colours are used only to distinguish certain sections of the script from other sections. The colours are aesthetical only, visual aids presented by the author for clarity, to enhance the reading experience.

- Green indicates project variables that can be altered from project to project.
- Orange indicates the set workings of the script. Across multiple projects no alterations need be made in these groups.
- Pink outlines the validation and checking nodes to ensure the script has executed correctly, outputting monitor-able charts.

The script is dissected further, into groups. The green phase has one group. The orange phase has three groups and the pink phase has one group. These groups in order of execution are:

- Input list of changes to the model.
- Counts changes and adds blocks to the chain.
- Filters out data code.
- Combines data code with input list
- Send to HTML

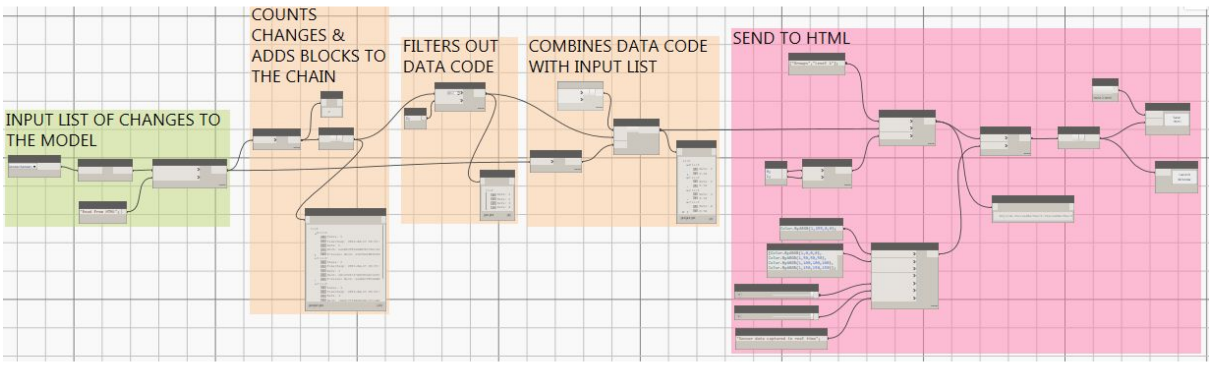

Fig. 5: Screenshot of complete dynamo Script developed by author for primary research testing. Source: Author.

Starting with the Green phase; this group is used at the beginning of the script to focus on a specific category within the BIM model, in this case, data devices (sensors); specifically capturing the energy reading from within the custom family parameter explained in section IV-b of this paper. The node "Family Types" allows the user to choose the category. The sensor category was chosen. The node "All Elements of Family Types" selects every sensor family in the project. The "Code Block" node inputs a search for the term "Read From HTML. This feeds into "Element.GetParameterValueByName". These two nodes combined, find the information within the “Read from HTML” parameter. These four nodes can be seen in Figure 6 below.

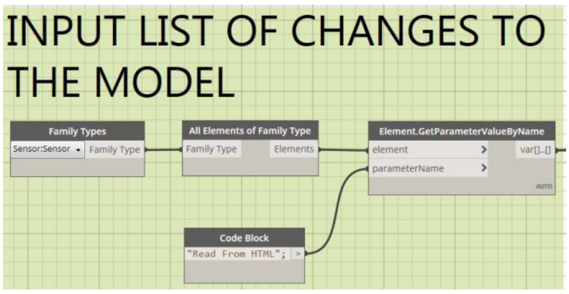

Fig. SEQ Figure * ARABIC 6: Green group, get "read from HTML" information. Source: Author.

With the information from the sensors selected, the next step was to progress to the orange phase. The first orange group: Counts changes and adds blocks to the chain. There is a custom node present which is highlighted in Figure 7. The author created a custom node that is essentially a novel Blockchain. (See Figure 7)

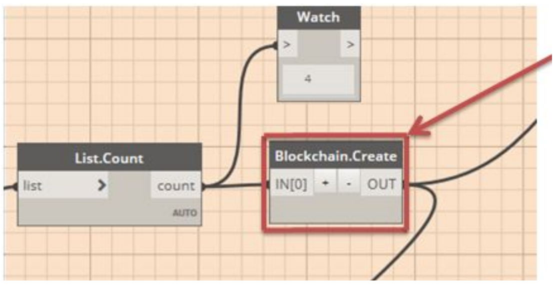

Fig. 7: Custom node (Blockchain)

Inside the highlighted custom node there is basic code. The code that was used can be found in the Appendix chapter of this paper. Figure 7 displays a watch node reporting the number four. Watch nodes only monitor and display information. The true path of the script is progressing from “List.Count” to “Blockchain.Create”. The watch node simply confirms that four counts of sensors are fed into the Blockchain. The custom “Blockchain.Create” node creates a genesis block, the first block of the Blockchain. It then continues to timestamp, produce and assign a hash number synonymous with that block. This process is done four times as there are four sensors sent through the Blockchain. Each sensor generates a block. Each block is timestamped, assigned a hash number and connected to the previous block via their individual and unique hash numbers. The information is timestamped and hashed together into an ongoing chain. This is the basic workings of a Blockchain. The output can be seen in Figure 8, an image of the watch node reporting on what transpired on the Blockchain: (See Figure 8)

Fig. 8: Output of custom Blockchain node

Moving onto the next group of nodes, filtering out each of the four Blocks was achieved by using the nodes “List.GetItemAtIndex” This node searches through the information seen in Figure 8 and takes the data to be further pushed through the Dynamo script. (See Figure 9)

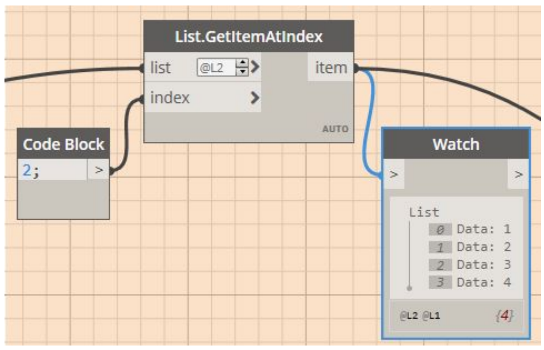

Fig. 9: Filtering out each Block

From there the data from the Blockchain is combined with the energy reading. (See Figure 10)

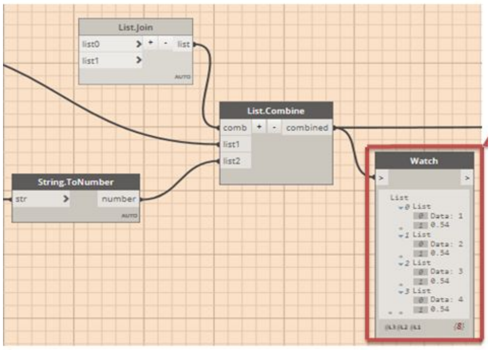

Fig. 10: Screenshot of Blockchain and energy data combination.

The watch node in Figure 10 consists of information that needs to be more universally legible. To represent this data in a more visually pleasing manner it was sent to the next group of nodes combining the information before sending it out into a bar chart for clear visual representation.

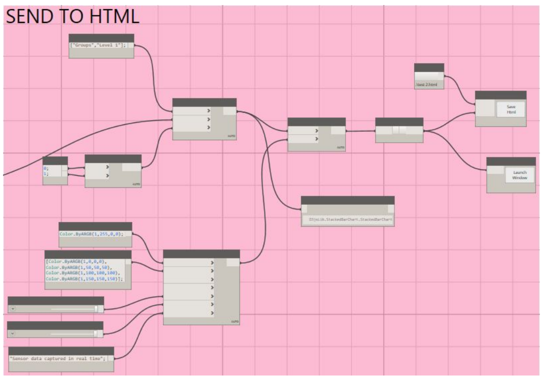

Fig. 11: Send information to HTML format

The next group, the pink phase, seen in Figure 11 is the validation phase. This phase checks nodes to ensure the script executed correctly, outputting monitor-able charts. To generate a chart the aesthetics of the chart must be defined. The majority of the nodes in the pink group are parameter rules that define how the chart is visually output from the dynamo script. The author spent minimal time on this phase, leaving default settings applied as it is the data in the graph, rather than the presentation of the graph, that is of most importance and relevance to this research. Achieving this, nodes were downloaded from the open source dynamo community and applied. Specifically nodes from the package “Archi-Lab Mandril” were used. (See Figure 12)

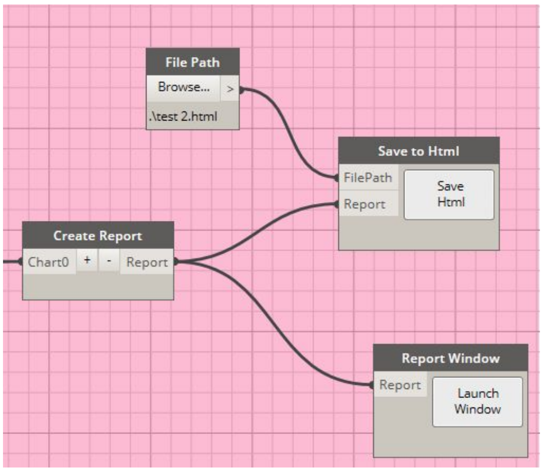

Fig. 12: Final step in the Dynamo script process.

V Findings and Discussion

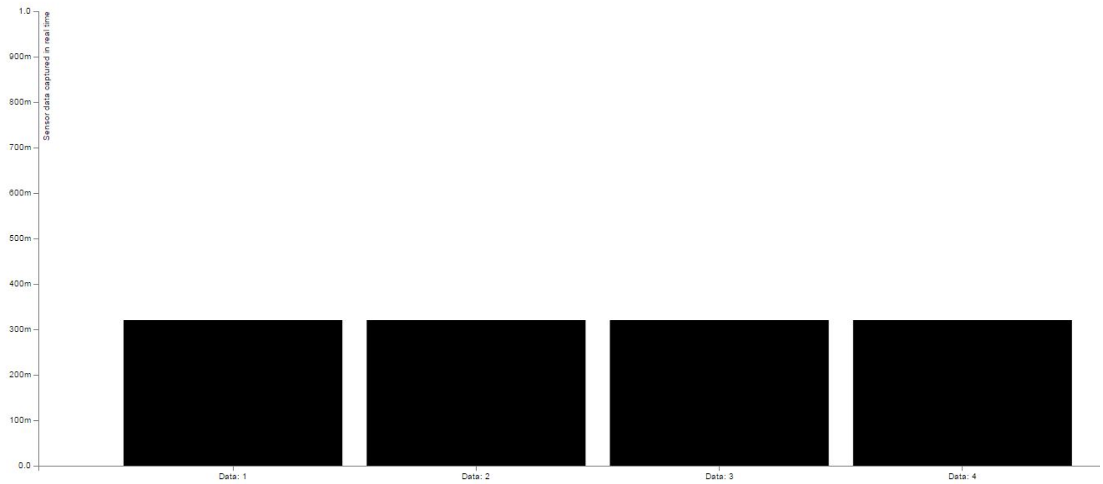

Fig. 13: Chart generated from Dynamo

The graph of Figure 13 was generated when the dynamo script completed. This graph embodies the success of this research, more graphs reporting on different tests with different predetermined variables can be found in the authors ePortfolio. In Figure 13, the information is exciting as this proves a Blockchain can record BIM data. With this in mind, it can be deduced that Blockchain technology has a place in a BIM setting. The research in this paper is in line with the opinions of Dr James Hearty, who stated the following when discussing the AEC industry:

> *"Should there not be a method to reward exceptional effort? Well, there is and it is called Blockchain" [45].*

The opinions of Dr James Hearty's were aforementioned in Section III-a of this paper. Similarly, Schleifer C Thomas also highlights the need for change in procurement within the AEC industry. Thomas notes lump-sum 'lowest bid wins' contracts don't work [48]. The BIM and Blockchain combination of technologies exhibited in the Research Testing section IV of this paper is evidence of a step forward in the direction toward answering a problem of procurement in the AEC industry. Blockchain is on the horizon as a new technology that could provide a trust based chain that enables one to be sure about transactions, (Schleifer 2018, Newton 2018, Council 2018, Kilkelly 2018, Sharman 2018, Dylan Yaga 2018, Silver 2018, Coyne 2018, Chao QU 2018, Penzes 2018) without intermediary financial institutions [49].

Clients want their project to move forward as rapidly as possible and want to be sure of the outcomes. However, at each stage of the process, most decision-making information only becomes known after the client has spent most of their money, this usually results in frugal clients [49]. Clients may become more frivolous rather than frugal, at the early stages of a project; if they are assured the property investment will generate not only rental revenue but energy sale commission as well, provided better than NZEB standards are achieved.

The greed seen today from clients who want their built assets built as cheaply as possible to turn over short term profits on their investment is not only ethically questionable but is having profound repercussions on the global environment. Buildings account for the majority of global energy consumption [50]. If the AEC industry can be incentivised to make better than NZEB standard buildings the environment will be spared a great deal. The short sightedness of building quickly and cheaply needs to come to an end, this attitude is throttling the evolution of innovation [49].

Smart grid energy ready buildings can help minimize the cost of electricity supply at the distribution grid level in three different ways. First, a smart meter allows for gathering of information for better predictions of electricity demand profiles of local consumers. Second, the electrical load of such buildings can be shifted based on time-of-use [51]. Finally, imbalance costs resulting from mismatches between forecasted supply and demand can be tackled by real-time demand response [52].

Technological advances in how and when financial transactions are made have great potential to positively impact procurement in construction. Blockchain could revolutionise how the supply chain is valued and compensated. Greater transparency and traceability of payments in the AEC industry also has the potential to signal and provide a measured understanding of where supplier value lies from sector to sector and from project to project. [53]

VI Conclusion

Blockchain technology is inherently distributed and BIM is inherently collaborative. In this light the two technologies seem destined to work in tandem. This research was carried out by an individual, the author. It is difficult to fully realise the power of pairing these two team oriented technologies when working in a silo. The study of these two distributed and collaborative technologies can be paired for a number of different applications. These new applications should be further researched by teams of capable industry professionals and academic specialists.

The author set out to investigate the potential of Blockchain Technology in a BIM setting. To discover incentivising ways of promoting better than NZEB design. The research question: If a building can produce more energy than it is consuming, is there an opportunity for the building owner and/or design team / building occupants to sell the surplus energy as a commodity? The result of answering this question positively has developed a potential for two "added value networks". The first, an added financial incentive for the design team to strive for the very best building performance, and the second, an incentive toward the building occupiers to conserve energy usage as this will leave more energy to sell and thus building up an "added value network" of people and places.

This research followed a small scale hypothetical testing scenario. The pertinent findings: Blockchain, by design a database, was successfully able to record and document information from a BIM model. This outcome was an assumption prior to the completion of testing. Now with proof, the author concludes, Blockchain can indeed present an opportunity to sell a surplus of energy as a commodity and share the income amongst different parties in a democratised way. Success was found in the area of running the BIM model data through a Blockchain. This provides a proof of concept. Applying this method to a full scale real-world better than NZEB building equip with sensors reporting real data goes beyond the scope of this research. However, this will be the evolution of the proof of concept, taking the proof of concept from tested theory into practice is the next step for the author.

With building procurement remaining a concern in the AEC industry, Blockchain technology can help aid answer that concern. The outcome of this research suggests that technological advancements are not a barrier to but rather the answer to procuring built assets. The barriers are, culture change and education; as Blockchain technology remains misunderstood by the mainstream. The technology will only become a revolutionary advancement when it becomes part of mainstream culture and the potential becomes common knowledge. Blockchain technology will then be adopted globally. The technology makes trust a tangible reality and trust is what the AEC industry lacks. The sooner the AEC industry harnesses this, the closer the industry will be to a better method of building procurement.

From this research of qualitative desktop literature studies and quantitative testing methods the author notes the tremendous value of Blockchain, a distributed ledger, when used specifically with a digital twin. All stakeholders will become aware of how much energy is produced by built assets and all stakeholders will know how much energy is consumed by built assets. None of this information can be altered as to do so would result in an obvious deviation from the set rules agreed by the rest of the stakeholders. If a built asset is successful in producing more energy than it consumes, smart contracts can be deployed on the Blockchain to sell the surplus energy back to the public and share the income amongst the design team in a democratised way. Therefore, it is in the financial interest of the design team to strive for better than NZEB standards. Noted in the Literature review:

> *"In the same way that the internet changed information services forever, Blockchain will transform services of value forever. The only question is: What form will this transformation take?" [13].*

The research in this paper highlighted one way this transformation could potentially materialise.

Overall this thesis, set out to answer one question via the completion of four main objectives. The first objective of this research was to implement a Literature Review; this was illustrated in section II of this paper. The second objective was to hypothesise a solution to be applied in a BIM setting. This objective was explained in section III. Full documentation of this process is covered in more detail in the authors ePortfolio. The third objective of this research: Progress the hypothesis from theory to tested theory, conducting rigorous test. One test was explained in full throughout section IV of this paper and more tests along with results and analysis can be found on the authors ePortfolio. The final objective of this research, analyse and report on the findings discussing future potential has been covered in both this section of the paper and the previous section.

Upon reflection after the completion of each project objective it is clear that the answer to the research question: If a building can produce more energy than it is consuming, is there an opportunity for the building owner and/or design team / building occupants to sell the surplus energy as a commodity: Is, yes. In turn, this results in “Added Value Networks” incentivising designers to provide quality energy producing buildings and incentivising people to conserve energy both for financial reward.

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IX APPENDIX

The following is the python code used in the custom node within the dynamo script:

```
import clr
import sys
sys.path.append(r'C:\Program Files (x86)\IronPython 2.7\Lib')
import hashlib
import datetime as date

def GenesisBlock():
    index = 0
    timestamp = date.datetime.now()
    data = "Genesis Block"
    hash = hashlib.sha256(index.ToString() + timestamp.ToString() + data.ToString()).hexdigest()
    previousHash = ""
    return Block(index, timestamp, data, hash, previousHash)

def Block(index, timestamp, data, hash, previousHash):
    return "Index: " + index.ToString(), "Timestamp: " + timestamp.ToString(), "Data: " + data.ToString(),
    "Hash: " + hash.ToString(), "Previous Hash: " + previousHash.ToString()

def NextBlock(lastBlock):
    str = lastBlock[0]
    rep = str.replace(" ","")
    split = rep.Split(":")
    thisIndex = float(split[1]) + 1
    thisTimestamp = date.datetime.now()
    thisData = thisIndex.ToString()
    thisHash = hashlib.sha256(thisIndex.ToString() + thisTimestamp.ToString() + thisData.ToString() +
    lastBlock[3].ToString()).hexdigest()
    str2 = lastBlock[3]
    rep2 = str2.replace(" ","")
    split2 = rep2.Split(":")
    thisPreviousHash = split2[1]
    return Block(thisIndex, thisTimestamp, thisData, thisHash, thisPreviousHash)

count = IN[0]

blockchain = [GenesisBlock()]
previousBlock = blockchain[0]

blockList = []
for i in range(0, count):
    addBlock = NextBlock(previousBlock)
    blockList.append(addBlock)
    previousBlock = addBlock

#Assign your output to the OUT variable.
OUT = blockList
```