A PARADIGM SHIFT IN
CONSTRUCTION PRODUCTIVITY

BIM + BLOCKCHAIN

HOW COULD BUSINESS LOOK TO CAPTITALISE?

2020

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1.0

INTRODUCTION

1.1 BACKGROUND & OVERALL AIM

1.1.1 CONSTRUCTION IN THE 21st CENTURY

Globally, construction is a critical industry, forecast to represent 14.7% of global GDP by 2030 (GCP & Oxford Economics, 2015). As such it underpins both economies and societies with few other sectors having such an impact on markets and the opportunity to provide new high-skilled commercial opportunities (HM Government, 2018). Construction however has struggled in evolving itself alongside other industries, with productivity inefficiency as a constant issue over the recent decades (House of Lords, 2018). Indeed, while other sectors from retail to manufacturing have transformed their efficiencies, boosted their productivity, and now embraced the digital age, construction has stubbornly remained largely unchanged for decades (KPMG, 2019).

Now with the progression from the 3rd to 4th industrial revolutions, 'Construction 4.0' (WEF, 2016) presents the industry with clear opportunities to embrace where previously it has faltered. The new reality of shortening time periods taken for digital disruption to permeate each new economic & societal environment progresses as the rate of innovation increases and each new technology network created justifies its use and value. (Deloitte, 2018). It is clear;
'We stand on the brink of a technological revolution that will fundamentally alter the way we live, work and relate to one another. In its scale, scope, and complexity, the transformation will be unlike anything humankind has experienced before. The 4th Industrial Revolution is building on the 3rd, the digital revolution that has been occurring since the middle of last century. It is characterised by the fusion of technologies that is blurring the lines between the physical, digital and biological spheres' (Schwab, 2017).

1.1.2 THE CONSTRUCTION PRODUCTIVITY CONUNDRUM

Globally across all advanced economies, for decades construction has recorded declining, stable, or at best slow growth in measured construction productivity. Although each country has its own set of challenges and priorities, it is an international issue within the industry as a whole (CIOB, 2016) even though construction and infrastructure is projected to grow in real term from \$10.9tr in 2017 to \$12.9tr in 2022, a percentage increase of 18.3% (GlobalData, 2018) and towards \$15.5tr by 2030 (GCP & Oxford Economics, 2015). With research revealing globally large-scale projects of all types consistently come in 80% over-budget and 20% over cost (Agarwal, et al., 2016), productivity solutions must be seen as the most significant opportunity in the industry needing evolution. With a global productivity gap of \$1.6tr existing the necessity for a targeted development of industry performance is evident (McKinsey, 2017).

Yet to increase productivity overall, it is crucial to look at the whole as well as the parts of a system and understand how each interacts with the other (CIOB, 2016). It is also imperative not to fall into the trap of perceiving increasing productivity as just a matter of employees within organisations working harder and 'smarter'. Higher productivity depends as much on the skills of the person undertaking the work as on the tools that a person and company has at their disposal when producing goods or delivering services (RIBA, 2018). With industry technology trends and wider societal changes happening now which represent both unprecedented risk and opportunity for the industry and its clients (Farmer, 2016), at the WEF Annual Meeting 2018, 61% of CEOs and government ministers outlined adopting advanced technologies on a large scale for the construction as critical (WEF, 2018). Therefore, 'if the opportunities technology suggests are not harnessed, the industry's problems may become overwhelming' (Farmer, 2016).

1.1.3 THE CONSTRUCTION INDUSTRY & DIGITAL DISRUPTION

While technology has always driven industry forward causing disruption, current emerging digital technologies fundamentally differ from those preceding. Three factors exist which are common to digital disruption itself;

Firstly, it knows no boundaries. Digital disruption creates radically more challenging consequences to adapt to than previous technology, due to its virtual character it is not bound by business, political or geographical boundaries simply due the fluidity of digital data. (Gartner, 2017). Secondly it dismantles hierarchies in favour of networks because the connected digital environment in which it occupies requires trust through collaborative data processes and transparency negating limiting top down control (WEF, 2016). Thirdly, it regularly slays cows. The digital environment enables assertion of new questions against common assumptions of how traditional markets and industry processes have operated to date, posing radical new methods and enabling the overcoming of traditional herd mentalities. (Matthews, et al., 2017)

While digital disruption predominantly exists outside of individual businesses normal ranges of vision, it is the innovative combinations of new or existing technologies arranged together, requiring different business models against the problematic focus in given industries, which produce disruptive outcome. Companies which ignore potential industry changing technologies risk becoming irrelevant. Consequently, as digital business continues to grow, the AECOO industry will be required to increase their ability in recognize, prioritizing and respond to digital disruption, with the one decision enterprises shouldn't make is to do nothing, this merely delays the inevitable disruption (Gartner, 2017) (See Fig 1.1).

With the AECOO industry perhaps the last surviving major industry that has not yet felt the full force of digital transformation (McKinsey, 2017), the possibilities in utilising innovative technologies to create new commercial opportunities working to solve the industries productivity concerns is clear.

Fig 1.1: *Core Industry 4.0 Digital Trends Towards the Digital Construction Organisation (Agarwal, et al., 2016)*

1.2.1 BIM (Building Information Management)

Over the past decade within the AECOO industry Building Information Management (BIM) has become an increasingly influential digital technology. While BIM has many definitions, common consensus outlines it as a process for combining information and technology to create a projects visual digital representation. Integrating data from many sources and evolving in parallel with the real project across its entire timeline, the model includes design, construction, and in-use operational information (Mordue, et al., 2015). 'In its fundamental form, BIM is a process that deals with the digital representations of real-life physical assets. At its centre is a computer model that holds a wide array of information about the assets such as 3D geometry, construction management information like time schedules and costs or operation and maintenance metrics' (ICE, 2018). As such BIM is a collaboratively generated and maintained data rich information source for the life of the design, building process, built entity and beyond secured through a centralised network (Boukara & Naamane, 2015). Its process therefore reorganises the traditionally fragmented information exchange between parties to a real-time centrally distributed network (See Fig 1.2).

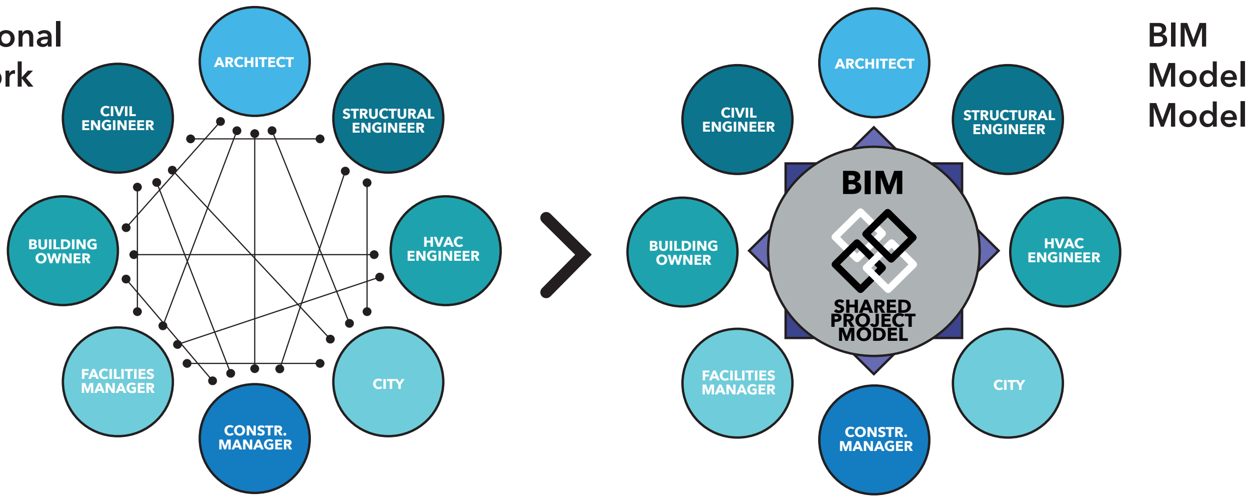


Fig 1.2: *Traditional & BIM Data Network Models (Mordue, et al., 2017)*

With BIM by its very nature very data-centric, the best way to establish trust is to trust the data itself, which is not the case today with conventional information exchange models between the different AECOO bodies (Newton, 2018). Therefore, traditionally the industry suffers from a fragmented structure and is "not set up to deal with trusting relationships, even though we need them, the process of procurement seems to be set against trust" (Matthews, et al., 2017).

1.2.2 BIM LEVEL 2 ADOPTION TO BIM LEVEL 3

In common with all technology, BIM has moved through different evolutions in capability, driving the incentive for its adoption. In 2016 UK government set an international benchmark, requiring all centrally procured government construction projects to use of BIM Level

2 (HM Treasury & Cabinet Office, 2016), consequently, industry awareness and adoption has increased steadily with Level 2 perceived as the foundation for the industries start to digital transformation. Future transformative technologies will then be able to build upon this foundation, helping to create the step-change in productivity and quality within the industry (NBS, 2018) with public sector adoption enabling BIM maturity across both government and commercial sectors, future evolutionary moves towards BIM Level 3 will support fully integrated collaborative data stream processes. Subsequently this would enable radical developments in each building's construction, operation and management lifecycle, paving the way for smarter, better connected cities (HM Treasury & Cabinet Office, 2016).

BIM Level 3 (See Fig 1.3) will enable the placing of data concerning the functional and design characteristics of a building at the heart of project planning and execution. Feedback loops about the performance of existing projects and structures will become increasingly possible leading to BIM becoming a self-enriching process, informing future project designs, and enabling companies to engage in long-term frameworks covering maintenance and repair, utilising data about the actual use of the asset to inform maintenance decisions (WEF, 2017).

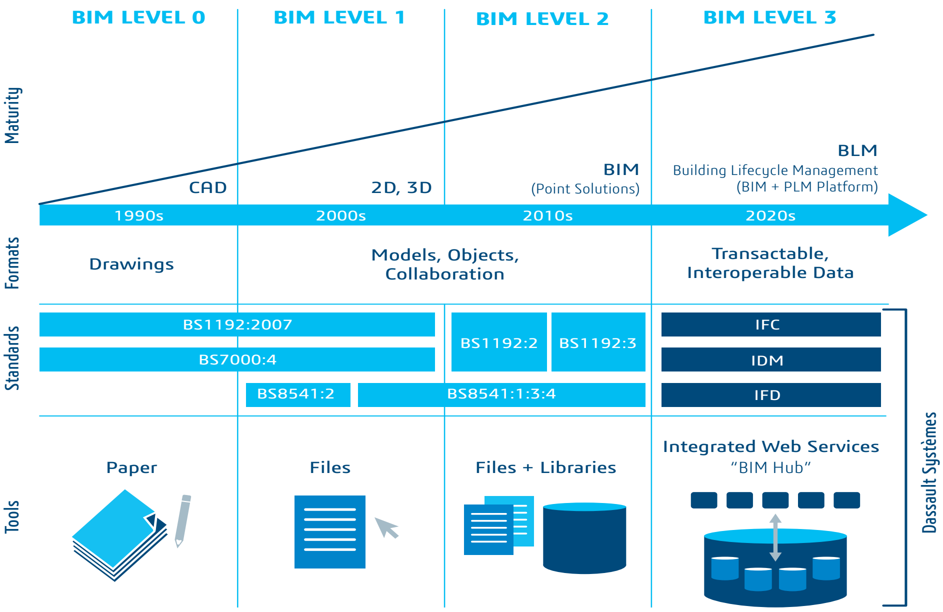


Fig 1.3: *The BIM Maturity Model by Mark Bew & Mervyn Richards (Dassault Systems, 2016)*

With the UK Government now investing £170m in the 'Transforming Construction: manufacturing Better Buildings' initiative for Digital Technologies including BIM, with the intension of increasing the efficiency of construction techniques (NBS, 2019), BIM's role is being shaped as central to the industries digital transformation (See Fig 1.4). Yet with it being the first truly national and global digital construction technology deployed, and a 'game changer' the industry must recognize is here to stay, in common with all innovation this presents both risks and opportunities (HM Government, 2015).

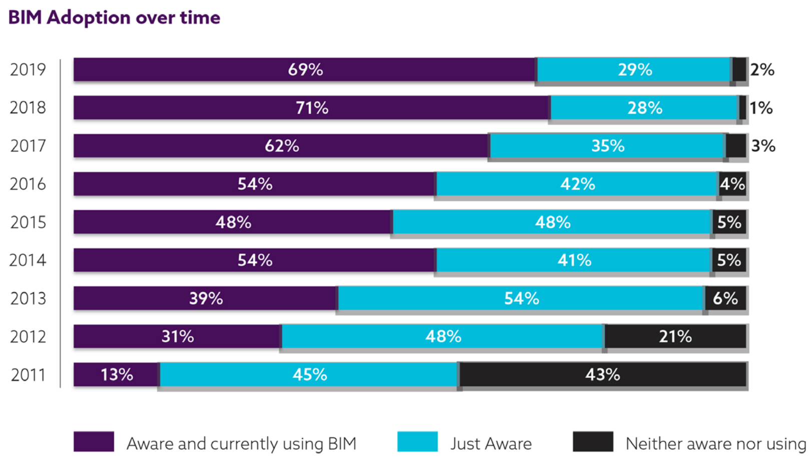


Fig 1.4: *BIM Adoption in UK AECOO Professionals. (NBS, 2019)*

1.3 BLOCKCHAIN & WHAT IT OFFERS

1.3.1 WHAT IS BLOCKCHAIN?

What if there were an internet of value – a secure platform, ledger, or database where buyers and sellers could store and exchange value without the need for traditional intermediaries? This is what blockchain technology proposes as the potential offer for businesses (Ferguson, 2018). Blockchain has been proclaimed as a game-changing technology across multiple industries, with its effect on the financial sector already present (Tapscott & Tapscott, 2017). Its suggested potential to streamline processes, manage identities and save money have given the technology a mystique that is perhaps enhanced by a lack of understanding about how it works by the general public and business leaders. Many sectors are exploring whether it is worth pursuing, not least of which the AEC industry (Lamb, 2018). A blockchain, can be described as a combination of existing technologies, built on the foundation of 4 key elements: (Olsen, et al., 2017) (See Fig 1.5).

1. **Distributed Ledger & P2P networks**
2. **Digital signatures – Merkle Tree**
3. **Consensus Algorithms / Protocols**
4. **Smart Contracts – Public Key**

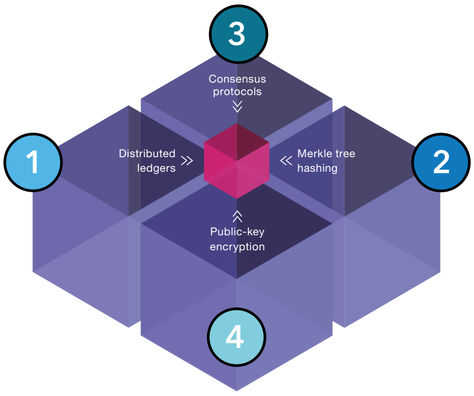
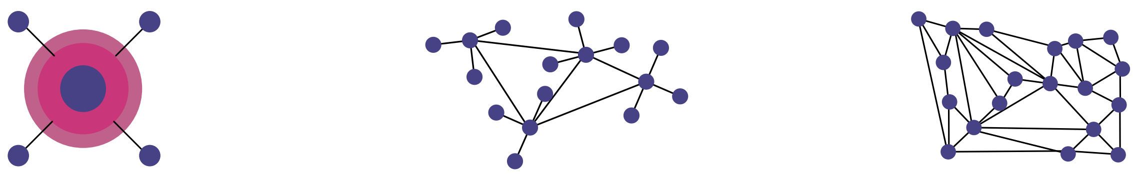


Fig 1.5: *Combination of Four Existing Technologies That Make Up Blockchain Technology (ARUP, 2019)*

First developed ten years ago as the underlying technology of Bitcoin, it combines economic incentive and cryptographic links between records and the distribution of data on a decentralised network that is available to all participants on a node system (Nakamoto, 2009). The technology makes it increasingly difficult the longer the chain of data, to change any specific node as all participants have access to exact copies of the information. (Zhang, et al., 2019). It is therefore seen to have the potential to enable the creation of the 'Internet of Value' (Visconti, 2019). Each blockchain network can be organised according to the requirements of use and the needs of the users with 3 structures used. (See fig 1.6)

3 TYPES OF BLOCKCHAIN:



CENTRALISED
A centralised database processes and stores information at a single location.

DE-CENTRALISED
A decentralised database processes & stores information at multi locations.

DISTRIBUTED
Distributed databases sit on multiple devices in the same location across interconnected computer networks.

Fig 1.6: *3 Types of Blockchain (ARUP, 2019)*

1.3.2 WHY NOW?

With the British Government establishing BIM as central to its digital revolution charge, it has not only put productivity at the heart of its economic policy, but also as a core plank of its new industrial strategy (Mace, 2018). As such 90% of RIBA surveyed professionals quantified new technologies were already transforming working methods, with over 80% asserting by 2030 architectural practices and the construction industry will be radically changed to present (RIBA, 2018). Therefore, with such current industrial and political acknowledgment for change, the present need for industry to embrace radical new technologies at their conceptual outset so the opportunity reshaping the industry for the better is simply too great (See Fig 1.7).

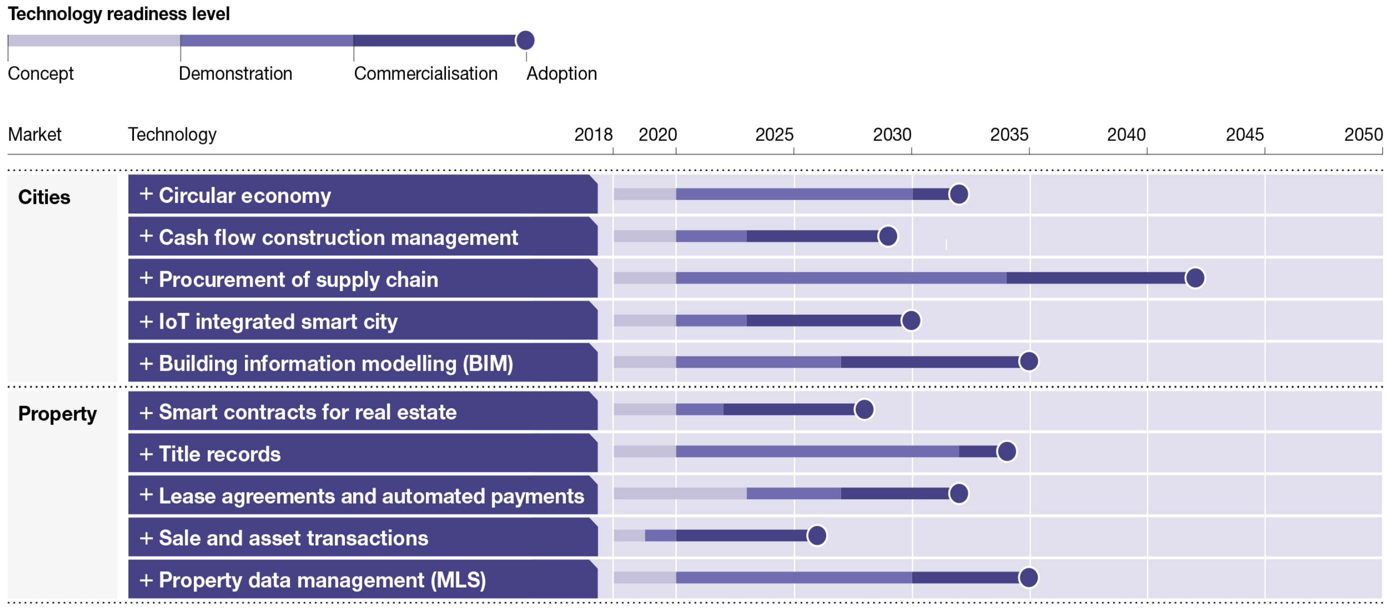


Fig 1.7: *Blockchain & Related Technology's & Case Study Sector Areas Relevant to AECOO. (ARUP, 2019)*

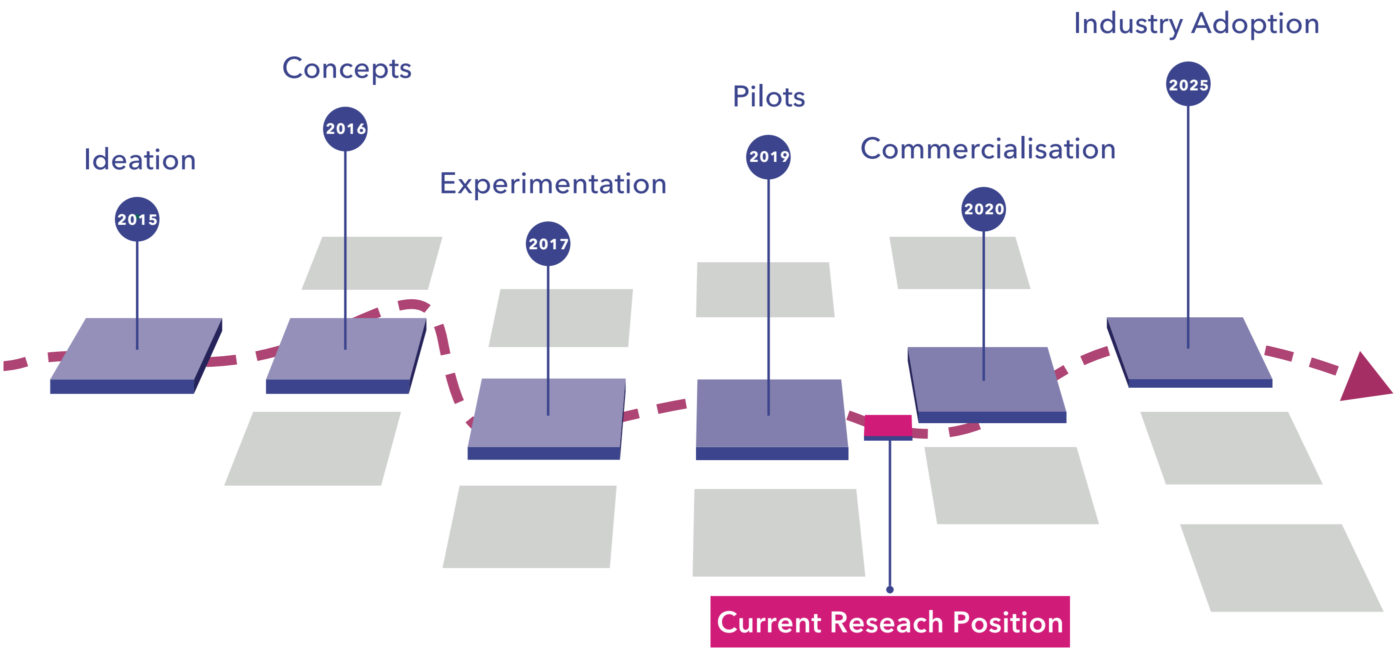


Fig 1.8: *Blockchain Industry Development Timeline (ARUP, 2019)*

1.3.3 IS BLOCKCHAIN WHAT THE CONSTRUCTION INDUSTRY NEEDS?

With the technology in its initial phase of development, not yet infiltrating the AECOO industry beyond R&D stages, collectively it is clear the construction industries problems will only evolve by encouraging data collaboration, using technologies that can boost productivity and efficiency while lessening risk (Tapscott & Vargas, 2019). With blockchain technology touted to be a major player of the future digital economy (Ferguson, 2018), and experts forecasting the use of blockchain in the real estate and construction sector to steadily expand (Thomson Reuters, 2018), construction has the opportunity to harness blockchains 'internet of value' creation for the realisation of BIM 3.0. The aim of all parties working in collaboration together on a single shared model, permitted to by increased levels of security, reliability and live data collection within an open, trusted environment cannot be ignored. Blockchains would provide an immutable record of changes, proving ownership of a model or digital component and decentralised common data environments. (ARUP, 2019). Therefore, the fundamental concept which enables the combination of BIM and Blockchain technology is their shared ability to serve as a single source of truth (SSOT). (ICE, 2018). The combination of BIM + Blockchain could have the potential as a platform for true collaboration where visual evidence of value transactions is written into a ledger, timestamped, gathered and thru consensus locked into a block, visible for the stakeholders to see with a platform like this fundamentally disrupting the design and construction industry (Matthews, et al., 2017).

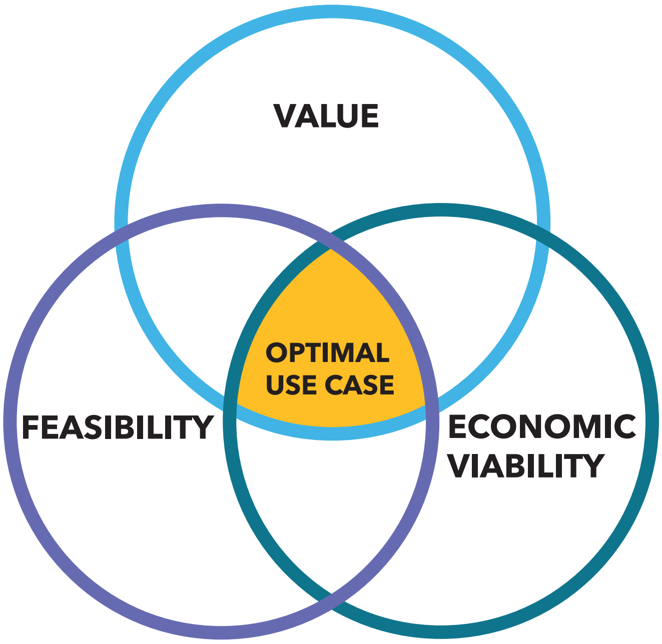
'What if there were an internet of value – a secure platform, ledger, or database where buyers and sellers could store and exchange value without the need for traditional intermediaries? This is what blockchain technology proposes as the potential offer for businesses' (Ferguson, 2018).

2.0

LITERATURE REVIEW

2.1 INTRODUCTION

With BIM already proven a commercially viable technology process, its relationship to blockchain is as yet untested. 'Golden Triangle Analysis' (Grealish, 2018) will be used to organise the research. By using this structure, consideration has been made of the interplay between the three elements of value, feasibility and economic viability, where the derived equilibrium sits and whether the technology stands to be validated and commercially viable. This will establish the optimum use case potential for both core sections to the literature review and frame the information from which further research questions will be structured. The optimum use case outcome will then be assessed against its potential for adoption.



Feasibility Overall

- Can the technology meet the business requirements?
- Can the participants achieve the prerequisities for success? Governance, collaboration, and integration.

Feasibility Overall

- Does the use case bring sufficient value to end-users to generate demand?
- Do they recognise the value?
- And do providers realise the value?

Feasibility Overall

- Are there sufficient economic incentives across participants?
- Will particiaption be profitable?
- Will there be enough participants to reach sufficient scale?

Fig 2.1: *New Technologies Golden Triangle Analysis (Grealish, 2018)*

2.2.1 NEW TECHNOLOGY COMMERCIALISATION & OPPORTUNITY CREATION FOR BUSINESS

With the AECOO industry internationally being one of the largest industrial sectors (Luo, et al., 2018) it inevitably has many global challenges (Lavikka, et al., 2018). Unfortunately it has not been innovative enough during past decades as verified by its historic flat productivity curve (Lavikka, et al., 2018) while still being required to make enormous improvements to efficiency to meet growing expectations from constant global urbanisation (Winch, 2003). Fundamentally, productivity improvements are driven by new technologies or new ways of organising production processes (Lee, 2019), therefore, the embrace and hopeful success of innovative new technologies through their commercialisation is crucial for the industries prosperity in today's increasingly competitive market (Cooper, 2000). Lately, while the emergence of new technologies BIM and Blockchain has been connected with extensive discussions regarding industrial and organisational development change, predicting how likely the successful commercialisation of such technologies will be, has always been a difficult task (Linderoth, 2017).

2.2.1.1 Technology: Feasibility

Williams and Edge (1996) likened emerging technology to a garden of 'forking paths' open to many possible futures (Bikker, 2010). Those involved in developing the technology for commercialisation are likely to have different visions for it, (Bijker, 2006), based on what they see as its potential and limitations (Kriz & Welch, 2018) at each new forked path, so each technologies development will inevitably be nonlinear and uncertain rather than a linear process. Consequently, it is recognised such 'new-to-the-world' radical innovations create situations for fundamental uncertainty (Dequech, 2011), in which the set of possible options as well as the outcomes of each option are unknown and unforeseeable (Packard, et al., 2017). Moreover, processes of social interaction and contestation through which technologies emerge will be shaped by broader macrolevel state and industry institution structures (Jasanoff, 2006). These conflicting interpretations may result in dilemmas over which technological direction to take with redirections, reversal and unintended consequences likely if not inevitable (Kriz & Welch, 2018). Therefore, both industry and businesses, when considering which technologies should become adopted have historically shunned such decisions. Such circumstances show business planning is a valuable activity for business and industry, even in uncertain and ambiguous situations (Delmar & Shane, 2003). It suggests this should facilitate new venture development with planning an important precursor to action because it provides frameworks within which subsequent action takes place (Ansoff, 1991) thereby facilitating the achievement of goals (Latham & Locke, 1991) supporting technology implementation decisions.

However, according to Goodrum et al (2011) awareness of particular technologies doesn't ensure adoption. A series of interrelated events are required for successful implementation. Increasing complexity of services and processes combined with the rapid pace of technological change and shorter life cycles of professional service methods leads to growing R&D and commercialisation cooperation between organisations (Kirchberger & Pohl, 2016). Therefore, technology commercialisation requires strong and varied capabilities, grounded in the firm's people, skills, knowledge, processes, systems and equipment (Zahra & Nielsen, 2002), for SME organisations which lack these resources, or sufficient technology specific knowledge, trust through cooperation might be the only possibility to bridge their technology deficit (Markman, et al., 2008), enabling diffusion so commercial viability on a broader scale.

2.2.1.2 Technology: Value

Schumpeter (1934) argued the creation of new technologies displacing incumbents through a process of creative destruction is a major source of innovation in the capitalist system. Therefore, successfully disruptive and innovative technologies create new market spaces. This transpires by overturning traditional industry norms, transforming markets and processes (Morrish, et al., 2019) through radical innovations that often are not as capable or useful as existing technology at the time of market entry but show significant potential to enhance capabilities in the future (Kassicieh, et al., 2002). How industry and business then commercialise 'new-to-the-world-technologies' (Kriz & Welch, 2018), creating value, requires successful innovation transfer to the market (Spann, et al., 1995).

Strategic management research outlines abilities to commercialise technological inventions as key drivers for firm success (Zahra & Nielsen, 2002). Whether commercialisation is successful or not, depends how consumers or business customers value the tech (Lo, et al., 2012), as not all technologies achieve market realisation (Markham & Lee, 2013). Frequently the problematic aspect is not the technological innovation itself, but the market commercialisation of the newly developed technology (Gans & Stern, 2003) due to industry practitioners being unsure which technologies should be implemented because of future uncertainties (Lavikka, et al., 2018). Yet since technologies potential to consistently enhance competency, its recognition as a crucial business management strategy (Drejer & Vinding, 2006) is essential.

For established firms the willingness to engage in the innovation commercialisation process is influenced by expectations towards values and returns captured from commercialisation (Nerkar & Shane, 2007). The ability to communicate each technologies value a significant issue when it is radical and unknown (Morrish, et al., 2019). In the construction industry, value is created primarily when services which embody new technologies outperform established methods or when the technology enables the development of completely new services which meet consumers requirements (Maine & Garnsey, 2006). How outperformance occurs relates to the attributes each technological innovation comprises of. This influences their likelihood of commercialisation in many ways making the study of all of them simultaneously empirically intractable (Nerkar & Shane, 2007). Even so it is these factors which increase the appropriability of returns from innovations leading industry to invest more heavily in those activities, increasing the likelihood of commercialisation (Levin, et al., 1987).

Yet it must be recognised technological change has a correlated relationship between firm creation, knowledge spill overs and economic growth. This relationship is precisely the core of Schumpeter's explanation for a capitalist system (Shane, 2001), with the probability a technological innovation will be commercialised through new firms creating varying with the nature of the technological opportunity discovered (Shane, 2001). Research indicates 3 attributes that make tech commercially successful (Shane, 2001). Firstly, scope of patent for the technology; the greater its scope, the greater the likelihood of new firms' creation to commercialise the patent covered innovation. (Shane, 2001). Secondly the degree to which innovations open new technology domains; how pioneering the technology is will influence its prospect for commercialisation because such ground-breaking characteristics increase incentives for the innovations forerunners to invest time and money in its commercialisation (Danneels & Kleinschmidt, 2001). Such innovations more likely than others to provide first mover and learning curve advantages (Nerkar & Shane, 2007). Thirdly the technology innovation age is relevant; in the beginning technological innovations are nascent and considerable time and effort must be invested before they can be transformed into commercially viable services (Jenson & Thursby, 2001). With new innovations values inherently uncertain at the outset, leading them to be eschewed by many potential early adopters (Utterback, 1994). Over time uncertainty is reduced, increasing information about their value, and likelihood for their commercialisation (Nerkar & Shane, 2007).

2.2.1.3 Technology: Economic Viability

Traditionally AEC leaders don't consider inter-organisational collaboration a prerequisite due to loosely combined industry structures encouraging sub-optimization, undermining inter-organizational collaborative development. Current relationships among each project's stakeholders tend to be short-term and market based due to lowest-price tender policies in the industry (Dubois & Gadde, 2002). Historically successful AEC industry companies aim to protect their business models as these have been successful in increasing their company's profitability. Yet protective behaviour can in-turn undermine innovation and inter-organizational collaborative development (Lavikka, et al., 2018), creating knowledge boundaries which challenge communication and coordination among the stakeholders (Lavikka, et al., 2015). This in turn stifles technologies from reaching their commercial validity and company heads developing the open-innovation IP strategy environments (Alexy, et al., 2009) such circumstances could encourage. So with growing pressure on introducing new technologies to the AECOO industry to benefit from the clear advantages offered (Skibnuewski, 2015), in current markets, both industry and companies within must know how, why and where the adoption of new technologies is needed, because it gives the ability to accelerate the rate of technology diffusion by assisting its adoption (Sepasgozar & Davis, 2018), commercially validating it.

Decision makers lack of knowledge implementation of new technologies individually across the value chain (Lavikka, et al., 2018). To enable its adoption through dissemination can be bridged through boundary spanners. Individuals or bodies delegated to handle the challenges of managing knowledge across boundaries (Levina & Vaast, 2005), steering discussions among stakeholders from different organisations towards shared knowledge, helping all to find common goals (Lavikka, et al., 2018). Crossing inter-organisational boundaries in a consortium type structure pooling knowledge, R&D and time to spur innovation, adoption and commercialisation across industry (Langan-Fox & Cooper, 2014) enables innovations of uncertain value to become magnified through a path-dependent process supported by the consortia. Over time as future potential adopters react to the social information (Greve & Seidel, 2015) provided by the consortia such externally sourced innovations which have broad scope, are pioneering and mature are more likely to be commercialised (Nerkar & Shane, 2007). Research suggests inverted U-shaped relationships between likelihoods of an innovations commercialisation and age when too long a time period has passed (Nerkar & Shane, 2007). Therefore, if a technology is too radical in its offering or developed in isolation, excessive time may pass until its economic viability is qualified. In such circumstances, opportunity for the offering has itself evolved or past and its commercialisation opportunity is often lost. With digitalization providing a basis for collaborative value creation through new forms of business and industry interaction, improved information sharing and transparency among stakeholders (Schobar & Hoff, 2016) is essential to the rapid evolutions of new technologies. However, a recent study by Schobar and Hoff (2016) found AEC decision makers uncertain in realising the benefits of digitalisation. Company decision makers struggled to understand how to manage changes from current construction practices to digitalised construction supply chains (Vass & Gustavsson, 2017) and understand economic benefits. Such studies show the lack of knowledge in how and why to change practices is one reason digital tools such as BIM have not yet stimulated change fully through the AEC industry (Fox & Hietanen, 2007), becoming commercially ubiquitous as was initially foreseen by technologies advocates. How then could new technology innovations to market not suffer similar concerns?

2.2.2 BIM, BLOCKCHAIN & THEIR RELATIONSHIP WITH THE CONSTRUCTION INDUSTRY

Post collapse of British multinational Carillion in 2018 (Rogers, 2018) the construction sectors record for poor productivity was again brought to the forefront of industry and authority attention (Chapman, 2018). Carillion's liquidation exemplified polar opposites of what productivity should be with its failure causing hundreds of millions in losses, infrastructure scheme delays, supply-chain business closures, 43,000 jobs effected (Verschoor, 2018) and questions asked at highest levels of government. Had Carillion been "more productive", transforming its skills towards new technologies, leading innovation in its management and business planning rigour, it might have avoided the calamities brought on itself (Sweet, 2018).

Unfortunately the familiarity of AECOO's problems can be arranged into a vicious cycle where low productivity leads to financial fragility, leading to lack of R&D and training which leads to further low productivity (Rogers, 2018). However, with digitisation seen by policy makers as the key evolutionary and strategic solution for AEC's productivity problems, disputes issues and slow adaption to change (Linderoth, 2017), the key initial challenge is one of culture, where most construction AEC companies do not see themselves in an evolutionary process and behave as if digital innovation will not impact them (Woodhead, et al., 2018). However, technology evolutions and changes happening outside construction are likely to have a transformative impact upon it (Rogers, 2019) with digital tools and algorithms combining to generate new usage potentials (Henfridsson, et al., 2018), triggering so called 'wakes' of innovation (Boland, et al., 2007). With digital technology becoming a fundamental phenomenon studied in innovation research (Nambisan, et al., 2017), consistent research demonstrates companies adoption and usage of new digital tools in their work practices revolve around how these tools are perceived as advantageous in performing their working tasks (Leonardi, 2011). These unique environments enable game changing ideas to emerge from the gestalt between technology-instances and the transcending technological waves percolating outwards (Woodhead, 2012). Yet the construction industry worth over $10tn each year, around 13% of world output. If productivity had matched that of manufacturing over the past 20 years, the world would be $1.6tn better off each year (Groves, 2017). Complacency is simply not an option the industry can afford. Now with industry entering the 'Fourth Industrial Revolution' (LeeMinHwa, et al., 2018) those AEC firms not embracing Industry 4.0 digitalisation will experience increasing levels of competition and profit squeeze. Being non-adapted and undifferentiated they become a customer's second choices behind tech savvy rivals (Woodhead, et al., 2018), so being pushed into a low-tech labour intensive marketplace, perpetuating the vicious productivity cycle further.

2.2.2.1 BIM & Blockchain: Feasibility

With construction experiencing ever significant developments in automation and digitalisation globally (Hass & Kim, 2002), the emergence of an increasingly adopted technology, BIM has become one of the most promising developments within the AECOO industry (Chen & Tang, 2019). Acknowledged to have transformational potential for the construction industry, it offers extensive in the way projects are designed, built and operated (Hoseini, et al., 2017). Based on a central data set worked on by a collective of difference professionals, studies show BIM implementation has substantial firm-level and sector-level effects reducing costs, avoiding mistakes and so increased productivity (Bryde, et al., 2013). However, BIM has its limitations and bears a number of critical shortcomings (Narwari & Ravindran, 2019). Firstly, BIM has no ability to track, record and archive changes and modifications to its models as they evolve (Kerosuo, et al., 2015). It cannot assign responsibilities and liabilities due to the overlap of roles and responsibilities between the different stakeholders inputting data into the model. This creates concern for ensuring intellectual property protection, risk allocation, privacy and third-party reliance (Turk & Klinc, 2017). Secondly it has insufficient cyber resilience with consequential risks and liability to data theft, tampering and other cyber-attacks. Thirdly is a lack of legal frameworks detailing model data ownership and legal contractual issues (Ahn, et al., 2015). Lastly there is no ability to link or enforce payment methods for works undertaken and data inputted contractually within the BIM model (Li, et al., 2019). Therefore BIM has specific flaws needing to be addressed (He, et al., 2017) if Level 3 is to become ubiquitous offering the industry the technology driven productivity opportunity its potential suggests.

Positioning itself as the technology suited to cover these deficiencies is Blockchain through DLT's, using smart contracts. Such digital infiltrating construction would enable stakeholders on each project spending less time in disputes, and will progressing quickly to negotiated settlements, cutting cost and time. (Woodley, 2019). Blockchains use of smart contracts as machine-readable pieces of code conforming to specific behaviours designed to self-execute upon pre-set obligations being met (Li, et al., 2019) have the potential to transform how organisations transact and suggest the ability to negotiate without the need for human interaction (Sklaroff, 2017). One core smart contract strength is they can act as powerful evidentiary trails demonstrating agreements made by all stakeholders (Cohn, et al., 2017). Blockchain smart contracts enable legal frameworks to underpin a BIM data environment promoting adoption and increasing trust and collaboration as the availability of real time, change resistant and hack resistant records of data with trustworthy time entries increases the reliability, integrity and transparency of the data (Li, et al., 2019) within the BIM model itself. Considering the key causes of disputes are due to lack of information and transparency, digitisation could well have an ameliorative effect on disputes as information liquidity, with each BIM model having a DLT ledger working alongside and extending through its supply chains (Woodley, 2019). Subsequently, non or late payment of contract terms (Wang, et al., 2017) could be resolved via automated payments coded into smart contracts protecting contractors, sub-contractors and the supply chain against late payments (Wang, et al., 2017) as well as reducing the risk of underpayments, improving efficiency through reduced pay-out times (Cohn, et al., 2017). Yet the key challenge presented for long-term contracts is transaction longevity, where a contract is coded today for execution in many years (Mason, 2017). With the ability to pass on the BIM model as a digital asset its smart contract code may be able to unlock asset functions on transfer, with royalty payments to the originators (Coyne & Onabolu, 2017) of the BIM models data. However, how this is formulated, technically and legally remains in flux.

Governmental regulations are therefore essential in developing an environment to promote use and integration of BIM, Blockchain and IOT services, overcoming problems of interoperability while providing a manageable system without inhibiting innovation (Li, et al., 2019). Regulations likely alleviate concerns towards trust in business not being replaced by algorithms instead of institutions and markets authorities (Lustig & Nardi, 2015) as well as the communities that govern blockchain agents' interactions (Maurer, et al., 2013). However, with the public sector accounting for 20/30% of total construction spending in America and European governmental frameworks contracts can be designed to nudge companies to adopt new technologies and to co-ordinate with each other more efficiently (Groves, 2017). It is the government with most to gain from increases in industry productivity, having both the power and incentive to break industry logjams disrupting the downward productivity cycle. Afterall governments are not just passive customers, they have the power to change the rules of the game and shape the market itself (Sweet, 2018).

Hierarchy is inherently competitive, and networks are inherently collaborative. Competition is efficient only when both sides have equal information. Disparities of information have led to the practice of creating government regulations that attempts to keep the game fair (Matthews, et al., 2017). With transparency perceived as a watchword for good governance, making information visible or at least accessible in a public way contributes to trust (Coyne & Onabolu, 2017). With government regulations and laws still unclear about the usage of blockchain technology, policies issued by governments are a concern for markets and organisations that can affect broader usage of blockchain for business objectives (Mougayar, 2016).

2.2.2.2 BIM & Blockchain: Value

With BIM's potential smart digital technologies linking through industry 4.0's IOT, all stakeholders across the whole process design, construction and operations management could co-operate with each other on a common platform (Liu, et al., 2019). BIM's added value as a disruptive technology is the creation of an entirely new value network (Matthews, et al., 2017) through centralisation of all stakeholders data feeding into the central BIM model. The more stakeholders contributing, be those smart technologies or AECOO professionals, then the greater value the BIM model pertains to have. However, while Blockchain evolves from its infancy stages, no one is yet able to really tap into the full power of BIM 3.0 (Doan, et al., 2019).

Yet in Blockchain and BIM, the AECOO industry needs to define the specific problems they are trying to solve, with the need to understand how to configure, design, and use blockchain technologies in unique ways to solve these issues (Felin & Lakhani, 2018). With research demonstrating the key productivity boost using conjoined technologies comes from carrying out more tasks simultaneously, rather than in sequence (Rogers, 2018) and excitement over blockchain spreads, established players and new entrants across many industries must search for ways to utilise and commercialise the technology (Felin & Zenger, 2016). The construction industry adopts a wait and see attitude becoming late adopters due to concerns large investments in technology will outpace the gains (Brynjolfsson, 1993). However, blockchains promise to be as fundamental as the internet in shaping how future business will be conducted, suggests wait and see attitudes could be costly (Felin & Lakhani, 2018). Especially at a point in time when industry could instead look to shape the manner in which the technology is developed and applied. Afterall the shared digital economy arguably amplifies, extends, and accelerates the creation of such technological innovation which in turn impact the urban environment (Coyne & Onabolu, 2017).

2.2.2.3 BIM & Blockchain: Viability

Technology usage by multiple firms creates collectives (Burton-Jones & Gallivan, 2007) with the benefit in organising stakeholders together increasing their ability to realise collective-level goals (Yoo, et al., 2010) and shared usage structures for the technology as a whole (Leonardi, 2013). While each digital innovation adopted draws on the diverse knowledge resources of each company's specialisms (Yoo, et al., 2010), understanding new digital-technology adoption as a multi-level process is crucial. Collective-level outcomes emerge on the basis of combinations of individual-level heterogeneous actions (Nambisan, et al., 2017) and are essential to understand both in how new technologies within Industry 4.0 environments could work in synergy, and what is required to support them.

With research highlighting new digital technologies, converged towards a shared usage structure, all individual stakeholders are then required to use the digital technology in a similar way (Verstegen, et al., 2019). Construction project collaboration involves high degrees of complexity presenting multiple challenges to all parties involved (Tee, et al., 2019) with effective collaboration requiring both coordination and cooperation (Health & Staudenmayer, 2000). Therefore better understanding in how to evolve collaborations using new technologies is key, given the interdependencies of construction projects have long been associated with inefficiency and organisational failures (Flyvberg, et al., 2009). With an essential goal of BIM's adoption being the improvement of collaboration in construction projects, BIM usage must be formalised in every new project with the different stakeholders in order to update protocols in later projects enabling more advanced collaborative design projects to be undertaken in future (Verstegen, et al., 2019). With each BIM model acting as a central data index for projects and linked to further information of materials, quality and costs for projects (Liu, et al., 2015), BIM's centralised models are able to serve as a 'single source of the truth' (SSOT) (Liu, et al., 2019) on each project undertaken.

Beyond technical shortcomings however, if BIM's technological advancement is to be the viably accepted construction industry solution, it must address the key underlying systemic industry issue through effective resolution (Li, et al., 2019). Structural fragmentation is the single main root cause of the industries underperformance (Rogers, 2018). It traditionally leads to an adversarial approach between differing parties involved on each project where the reality is by minimising information transfer between parties within a hierarchy of different bodies involved on each project, an inherently competitive environment is created (Matthews, et al., 2017). Fragmentation can be resolved through increased collaboration and the building of trust between parties (Fellows & Liu, 2012). However, in order to establish trust, the stakeholders need to provide evidence of trust. Collaboration based around a shared BIM model is one method to provide visible evidence of trust, however a distributed ledger of transactions based on blockchain is another (Matthews, et al., 2017). Ever greater digitalisation relationships should facilitate better collaboration and discourage loss of trust and adversarial relationships (Woodley, 2019). Could therefore blockchain enhanced BIM implementation assist to address the above mentioned challenges in both managing information on each project and potentially solving challenges that hinder the use and potential of BIM (Liu, et al., 2019).

Blockchain platforms raise questions around scalability, decentralisation, modularity, interoperability, and governance challenges faced by different stakeholders, including new types of value creation (Constantinides, et al., 2018). However, in the internet age, network structures are more efficient and massively scalable. As with all social revolutions, people and businesses naturally reorganise to the system that provides better security, greater fault tolerance, ease of regulation, and greater market efficiencies (Matthews, et al., 2017). Blockchain could be a solution to many issues slowing BIM adoption such as limited collaboration and information sharing (Li, et al., 2019) as the industry moves towards Level 3 adoption. Unfortunately for business, there is little guidance on Blockchain technology and solutions in existence today and how these might affect businesses and business models (Morkunas, et al., 2019).

Blockchain is here, and while many have predicted its demise, the idea of blockchain software has only increased in applicability. Therefore, convergence of BIM and Blockchain will not seek permission to disrupt the design and engineering process, it is perhaps inevitable. (Matthews, et al., 2017). The task facing the AECOO industry is, with the emerging technologies of BIM and Blockchain, one of great difficulty and opportunity (Rogers, 2019), and to ensure changes occur for the better of the industry (Matthews, et al., 2017). Even so, consideration should be given to the fact that just because blockchain could provide a solution to the construction industry challenges, it is not necessarily the best or most efficient option; all other options should be explored when considering technological advancement (Li, et al., 2019).

2.2.3 ADOPTION OF RADICAL INNOVATION

Radical technological innovation represents development and implementation of new services enabling fundamental improvements in operational efficiencies, market interactions, and fulfilment of new stakeholder needs (Gopalakrishnan & Damanpour, 1997). With the diffusion and adoption of innovation within the AECOO industry context persistently overlooked (Hosseini, et al., 2015), it is necessary to understand how the adoption of radical innovations for firms enhances their competitive position, safeguarding long-term success and offers opportunity for the industry. With research revealing the degree to which radical innovation which departs from the norm, enhances firm performance (Gopalakrishnan, 2000), inevitably it is disruptive to company competencies enabling changes to existing structural and technological principles companies use (Damanpour & Aravind, 2011). Causing considerable changes to industry dynamics, the entry of new and faltering of established companies, alongside instability of the traditional market structures (Abernathy & Utterback, 1978) is inevitable.

While research maintains the adoption of radical technological innovation requires new organisational procedures, routines, capabilities and management practices (Chandy, et al., 2003), established firms often fall behind start-ups in adopting such innovations because of difficulties in breaking away from or evolving organisational routines and cultures (Chang, et al., 2012). Research argues development of radical innovations requires resource allocation and recognition of market opportunities necessitating paradigm shifts in organisational mental models (Bao, et al., 2012). Furthermore, such innovation adoption demands new business models to support the exploitation and application of those innovations (Sainio, et al., 2012). So, while large incumbents having more opportunities to develop radical innovation, the change required provides them with fewer incentives to do so (Chandy & Tellis, 2000).

Large incumbent firms are not likely as first mover radical innovation adopters, they tend to be slow adjusting their service offerings when radical innovations are introduced by new entrants (Henderson, 1993). Researchers have concluded radical innovations are developed in firms with experimental cultures, entrepreneurial climates, and strong technical competencies (Damanpour & Wischnevsky, 2006) often found in dynamic and competitive environments (Miller & Friesen, 1982). How then is it then AECOO industry suffers such poor technological innovation within what is a creative yet competitive environment? (Hosseini, et al., 2015). Research suggests it is the adversity individual companies face in overcoming market uncertainty when highly uncertain radical innovation adoption is proposed (Chang, et al., 2012), consequently limiting the industry to purely incremental innovation adoption (Ringberg, et al., 2019).

While radically innovated new technology is typically referred to as the driver of change, revisiting its adoption outlines how cascading adoption can have unanticipated consequences. New technologies are related to knowledge and intentions of past initiatives, but they often lead to unforeseen consequences alongside new technology developments (RIngberg, et al., 2019). While such adoption characteristically generates widespread positive externalities benefiting other companies through technological spill over, in-turn leading to follow-on innovations introduced by imitators (Colombo, et al., 2015). Consequences broaden the competitive landscape creating new market opportunities' (Bao, et al., 2012), adverse societal effects can generate negative consequences to the perceived value innovation adopters claim to hold. (Khessina, et al., 2018). Therefore, in the context of technology adoption within the AECOO industry, such externalities provide both pause for consideration and what values the industry intends to embody. Alongside they also present the opportunity scope for further value creation through such follow-on innovators or through firms acquiring complementary assets looking to capitalise from other further technological and demand externalities created by the radical innovation (Colombo, et al., 2015).

With the timing of incumbent firms' adoption crucial for the overall progressive acceptance of the innovation (Carter & Salimath, 2019), early adopters possess greater pre-exploitative learning capabilities enabling faster and more efficient issue interpretation alongside perceptions they possess greater technological knowledge and commercialisation flexibility advantages over rivals. This arguably should motivate early adoption even in the face of extreme uncertainty (Carter & Salimath, 2019).

With the pace of evolution in this field gaining increased traction, new discoveries constantly change the goal posts and direction of the conversation. Consequentially there is still limited academic and journal material on the subject.

3.0

METHODOLOGY

3.1 INTRODUCTION

An interdisciplinary approach was taken, using problem identifications and analysis. Key sources of secondary research based on current published academic works and periodicals was analysed within the literary review to inform the specific focus for the primary research interviews. These were conducted with the core construction project stakeholders for the proposed BIM and Blockchain Level 3 innovation (See Fig 3.1).

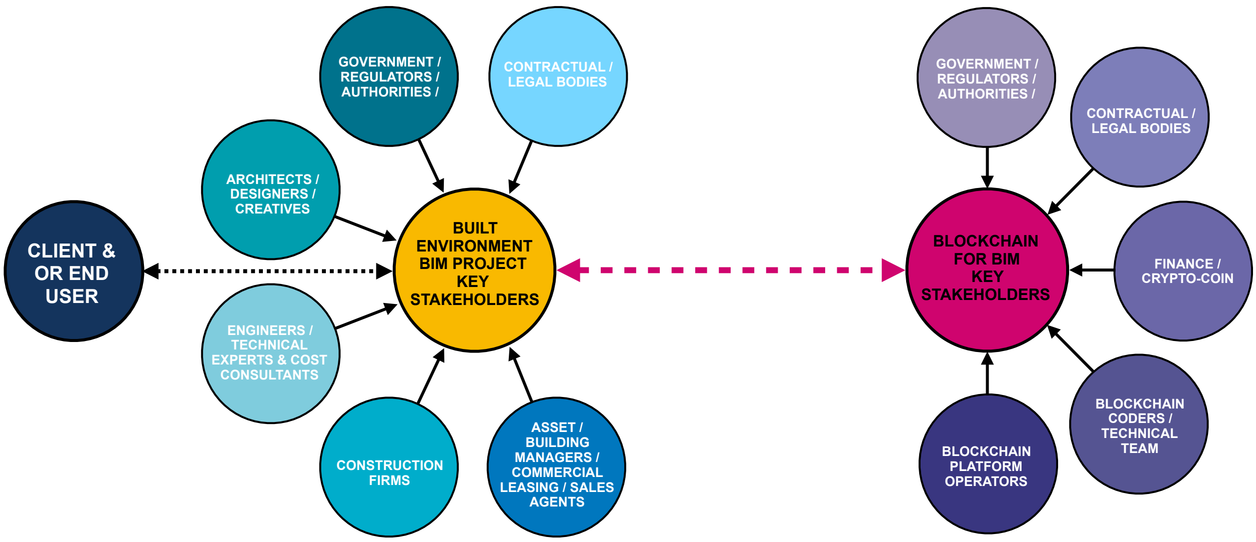


Fig 3.1: *BIM & Blockchain Key Stakeholders*

The following stages were followed;

1. Defining the research question, context & crucial boundaries.
2. Frame the project by formulating the research design, data analysis, coding, presenting of findings, analysis, and recommendations.
3. Organize the report from broad overviews and findings to detailed specifics.

This allowed development of a qualitative methodology, pursuing analysis under an inductive approach. Synthesise of all primary and secondary research to enable recommendations was undertaken.

3.2.1 AIM

To explore the question; BIM and Blockchain Adoption – The next Paradigm shift in Construction Industry Productivity? How should Business look to capitalise?

3.2.3 Research Design: Deductive, Inductive or Abductive

Research data becomes significant, contributing to knowledge when it is viewed in relation to theoretical concerns (Bryman, et al., 2019). Consequently, deductive, inductive and abductive approaches must be considered;

- Deductive derives a hypothesis from existing theory and the empirical world is then explored, and data collected, in order to test the truth or falsity of the hypothesis (Wilson, 2014).

- The Inductive approach to research being where the researcher begins with as open a mind and as few preconceptions as possible, allowing theory to emerge from the data gathered (Znaniecki, 1934).

- Abduction is used to make logical inferences about the world. Furthermore, abduction offers great promise as a potential primary mode of reasoning for qualitative research (Given, 2008).

Considering the different strengths and weaknesses of all three approaches through Bryman et al (2019) (See Appendix 1 - Table 3.1) alongside the intended aims of the research piece, 'Inductive Research' is the most appropriate approach due to the following reasons. Firstly, both the early stage nature of the research field, the broad approach to data collection, the search for patterns from observations in the findings and the development of explanations and theories from these (Bernard, 2011). Secondly, the process beginning with personal observations of the world, then organised into generalisations and trends (Neuman, 2013). Thirdly, inductive reasoning sits with 'Grounded Theory,' (GT) and as such is concerned with the generation of theory substantiated by systematically gathered and analysed data (Glaser & Strauss, 1967).

3.2.3 QUALITATIVE RESEARCH

Inductive research is 'qualitative' with the primary data research focus for the project being through interviews. The author used a six-stage structure in order to develop the qualitative research approach outlined (See Fig 3.2). This was used as a general guideline as it could not be assumed the qualitative approach using the research data collection and analysis stages would enable the structure to be followed rigidly.

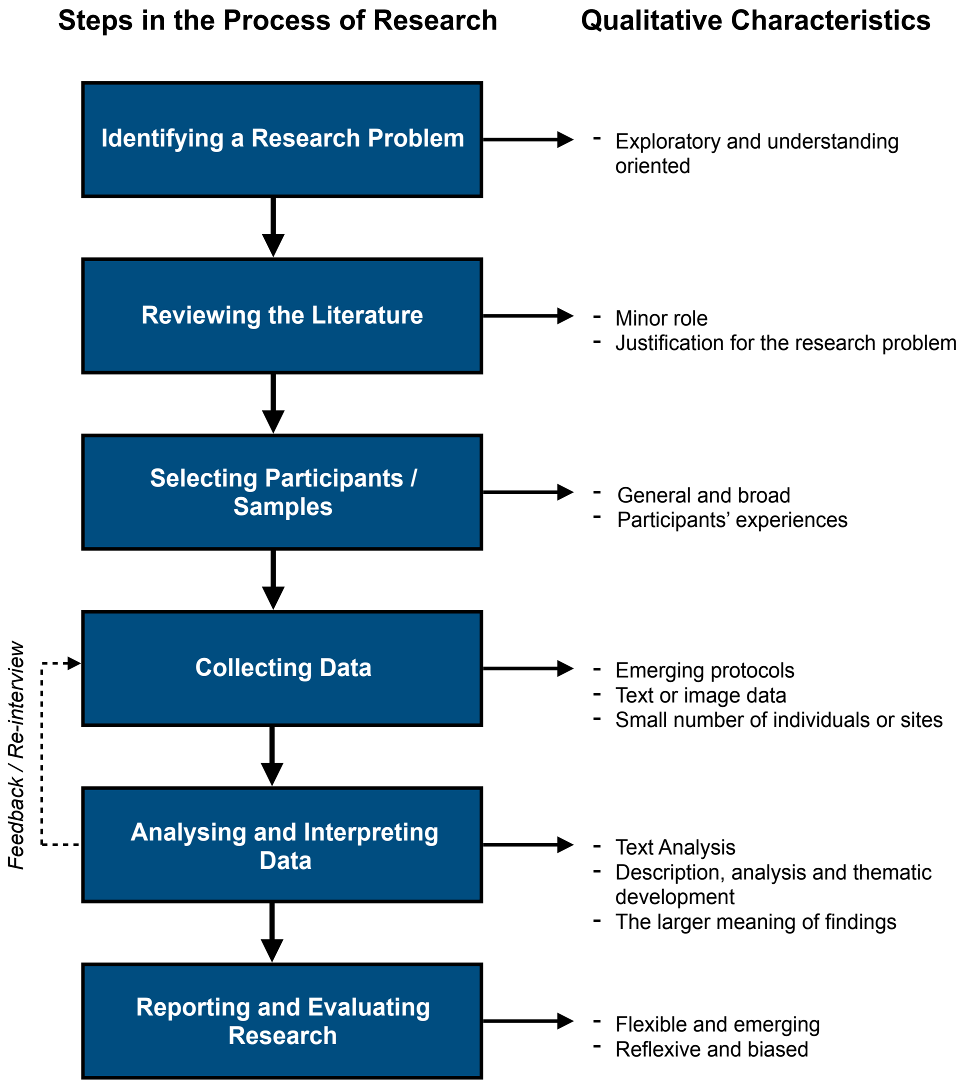


Fig 3.2: *Qualitative Research Framework & Characteristics (Creswell, 2011)*

3.3.1 PRIMARY DATA

Qualitative interviews were undertaken as was suitable for the inductive approach applied. Interviews provided an effective direct data collection method, with the intention to access the core of each interviewee's interpretation on the subject. They 'provide opportunities for mutual discovery, understanding, reflections and explanations via a path that is organic, adaptive and oftentimes energising, so elucidating subjectively lived experiences and viewpoints from the respondent's perspective' (Tracy, 2019).

Interviews were conducted via a Semi Structured Interview (SSI) approach, questioning the industry professionals selected using the same template of questions. This interview method provided opportunities for mutual discovery, understanding, reflections and explanations each via an organic path, adaptive and oftentimes energising, so elucidating subjectively lived experiences and viewpoints from the respondent's perspective (Tracy, 2019).

3.3.2 INTERVIEW QUESTIONS CONSTRUCTION

All interviewees were questioned using the same template of questions to enable reliable, comparable qualitative interview data. 'Interview questions' were then developed, following a pre-set list of topics, questions and sub questions derived from the literature review to act as a structure for each interview. However, by using SSI's the intension was to follow the topical trajectories in each conversation that may stray from the guide when it was appropriate. To see the 'Interview Questions' refer Appendix 3.

Fig 3.3: *Interview Questions Sections*

Each interview was 'non-standardised,' being individually conducted interviews one to one in person, by skype or telephone. Open-ended questions enabled the interviewee, to follow relevant topics which strayed from the specific interview questions and provided opportunity for identifying new ways of seeing and understanding the BMP topic questions at hand. Undertaken due to the authors intension to discover what each individuals' independent thoughts were on the question's topics (Newcomer, et al., 2015). With each interviewee being a significant figure in their respective sector and of relevance along the construction or blockchain open questions were required to better enable relationships between differing parties to be discovered and the trends to evolve accordingly. Also due to the interviewees senior positions and the studies time constraints it was recognised an SSI approach would be better suited due to the inability to follow up all interviewees with further questions (Bernard, 1988).

3.3.3 INTERVIEW SAMPLINGS

A maximum variation purposive sampling approach (Battaglia, 2011) was chosen when selecting the professionals within the two technologies value chains of BIM and Blockchain combined technology adoption for the AECOO industry. The choice of sampling method, was heavily related to qualitative research in the identification and selection of information rich cases enabling the most effective use of the authors limited resources (Patton, 2002).

Professionals were identified specifically due to their knowledge and experienced in the phenomena of research (Cresswell & Plano-Clark, 2011). The key rational in selecting this technique concerned firstly, the placing of the thesis research questions at the centre of the sampling consideration and secondly this approach enabled selection of professionals interviewed most suitable to answer the research questions posed. Therefore, the interviewees differed in physiognomies, both in professional background, industry, age and geographic location. While consideration was made in selecting interviewees with industry seniority and exposure to the questions material, the author none the less in looking to develop theory based on research from the outset so remained open to be surprised by the findings (Alvesson & Kärreman, 2007). Finally, due to the limitation of sampling effected by the inevitable subjectivity of the author concerning the selecting procedure, purposive sampling was appropriate for the small sample volume, from a restricted population definition, when the extrapolation of the sampling is to the wider population is not within the aims of the research.

Secondly a maximum variation approach was used. This was due to the aim in establishing whether shared patterns across each of the different stakeholders' industries would emerging out of heterogeneity. The approaches suitability to document unique and diverse variations that emerged in adapting to different variations in the environment the author researched was also recognised (Patton, 2002).

Once interviews commenced the author established elements from sequential sampling (Teddlie & Yu, 2007), due to both interview sampling decisions being made on the basis of information yielded as the research progressed and also the evolving sample size being effected by interviewees agreeing or withdrawing from interviews. Ultimately the author started with a core sample, which progressively increased to a collective sample size outlining conclusive findings against the research questions. The interviews themselves also presented opportunity to evolve to snowball sampling, (Goodman, 1961), as those interviewed offered up contacts to further approach for interview. This enabled the evolution of a broad spectrum of BIM construction professionals, blockchain technologists and professional advisors to be interviewed. Hence, due to the targeted nature of my research needing professionals from such areas of expertise, it was 'necessary to locate excellent participants to obtain excellent data' (Morse, 2007), which snowball sampling positively reinforced. The interviews & interviewees covered key positions in the BIM & potential Blockchain use in construction (See Table 3.2). This enabled an industry wide data pool of qualitative interview data facilitating differing answers to each question asked to become apparent. The diverse professional backgrounds and geographical locations enabled the author to achieve greater insights into the industry and the opportunities for BIM and Blockchain across all parties. For summary of all Interviews refer Appendix 4

INTERVIEWEE		TITLE / ROLE	SPECIALISM	COMPANY / REPRESENTIVE BODY	INDUSTRY / SECTOR
1	Interviewee 1	Founder & CEO	Architecture & Technology into Industry	Office Sian Architects	Architecture
2	Interviewee 2	Senior Director	Engineering & Technology & Consultancy	Atkins Acuity	Engineering
3	Interviewee 3	Global Lead Partner	Engineering, Human Resources & Technology in the Workplace - The Future of Work	Deloitte	Architecture, Engineering & Consultancy
4	Interviewee 4	Director	QS and Project Cost Consultant Head	Currie & Brown	Cost Consultant Engineering
5	Interviewee 5	Director, Head of India & SE Asia	Construction & Engineering	WSP	Construction Engineering
6	Interviewee 6	Director	Commercial Property Operations Bit Coin Miner, Blockchain Expert and	Jones Lang LaSalle	Buildings Operations
7	Interviewee 7	Partner	Head of Innovation & Legal Technology in Construction	Addleshaw Goddard LLP	Law
8	Interviewee 8	Founder & CEO	Blockchain Digital Banking & Regulation advisor to UK Government	DAG Global	Finance
9	Interviewee 9	Director	Lead Digital Transformation Consultant	EY	Digital Technology Consultancy
10	Interviewee 10	Consultant Blockchain Expert	Blockchain and Blockchain in Construction	ARUP	Engineering, BIM & Blockchain Engineering
11	Interviewee 11	Digital Industry Lead	Digital Industry lead, Blockchain entrepreneur start-up specialist & Regulations expert	European Institute of Innovation & Technology	Blockchain
12	Interviewee 12	Director	Corda Blockchain platforms	R3	Blockchain
13	Interviewee 13	Late Lord Mayor of London	Regulation to Government & Industry Support	Lord Mayor of London	Industry Support & Legislation

Table 3.2: *Interviewee Details*

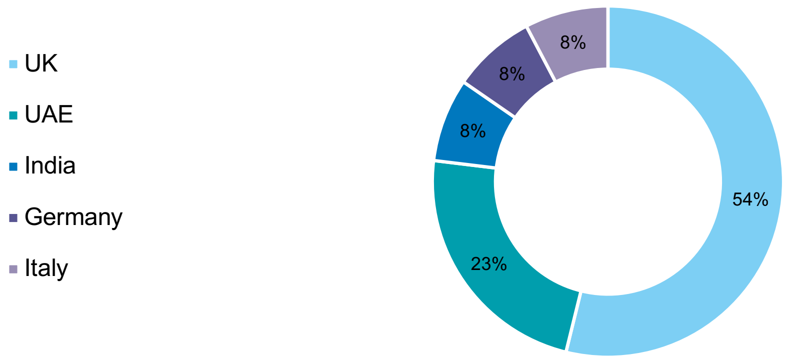


Fig 3.4: *Interviewee Professions*

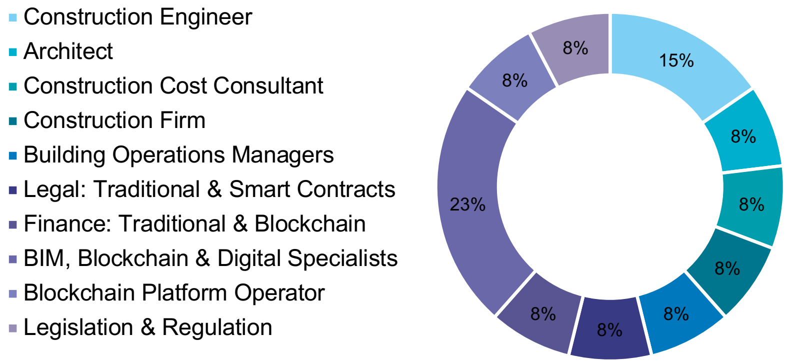


Fig 3.5: *Interviewee Geographical Locations*

3.4 DATA ANALYSIS & RESULTS

3.4.1 METHOD OF DATA ANALYSIS

- **Interview Analysis & Reporting SSI**

Appraisal of findings from the analysis was intended to yield a depth of understanding towards BIM and Blockchains viability, value creation opportunity and commercialisation within in the construction industry. Through the use of qualitative SSI's, the authors intended use of open questions, however if interviewees provided definitive answers, suggestive of closed questions these likely provided quantitative information so quantifiable statistical data which could be cited and or tabulated.

Interview transcripts coding through a 2-stage process enabled the consolidation of themes found through all answers given to the interview questions. Techniques to code open ended answers were utilised to generate data, numbers and trend analysis as the basis for the intended inductive theory formation. Outlier 'surprising' data was included in order for the findings and formulated theory to be accurately representative of data collected against the overall question and resultant data trends.

- **Method Analysis: Grounded Theory**

Due to the adoption of 'Inductive Reasoning,' GT was undertaken where theories around each interview question and the overall thesis were created through the collection and analysis of the qualitative data gathered. With each part informing the other, in order to construct theories of the phenomenon under study, GT was able to provide a rigorous yet flexible framework beginning with exploring and analysing inductive interview data leading to developments of theory grounded in data to emerge (Thornberg & Charmaz, 2014).

Therefore, the GT analysis required establishing repeating themes by reviewing the data and coding emergent themes with keywords and phrases, then grouping and categorising through relationship identification. It was these categories created from the codes which were used as foundations for new theory development. Yet with no ridged structure and rules for process, the author was required to undertake the analysis on his own. Proving labour intensive, it required devoted time for both data collection and analysis (Kolb, 2012).

3.4.2 CODING PROCESS

Undertaking a 2-stage coding cycle process, an 'Affective Method' was used to investigate the subjective qualities of the interviewees human experiences through a 'Values Coding' (Saldana, 2009) process as the appropriate coding method for the 1st cycle against the interview transcripts. The process enabled depiction of the interviewee's language, perspectives and worldviews on each question's answers.

Once each interview concluded and transcripts were compiled, the 1st coding cycle was undertaken, reading through and outlining the key overviews in summary words or phrases for each answer as a synopsis of what the interviewee discussed in response to each question. These were then compiled according to each question and interviewees respective codes.

Second cycle coding was then undertaken to restructure and condense the array of initial analytic coded details using 'Pattern Coding' (Saldana, 2009) grouping summaries into smaller numbers of themes and again reinforcing the use of 'Inductive Reasoning.' These provided the key categories against each question interviewees had expressed most vividly.

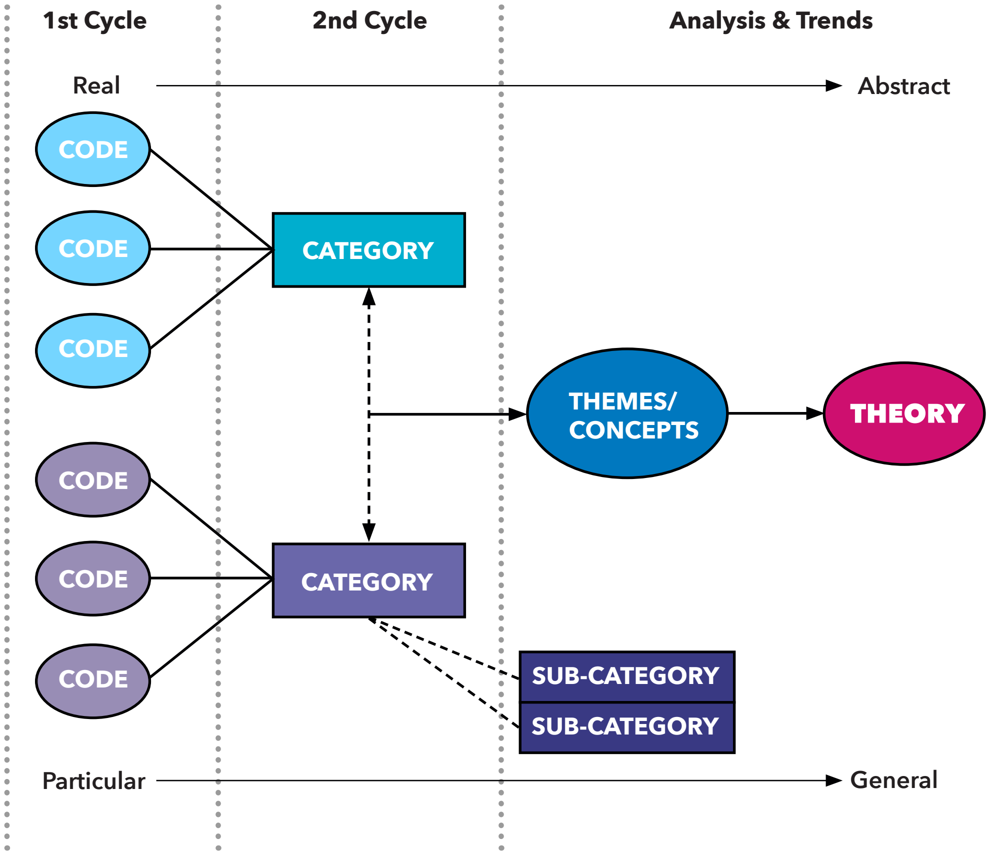


Fig 3.6: *Streamlined Codes to Theory Model for Qualitative Inquiry (Saldaña, 2015)*

3.4.3 ANALYSIS TO INSIGHTS

In order to generate clear trends against each question, all categories generated by each interviewee were mapped to reveal emergent sequences and response trends of my codes and categories. This enabled quantitative data to be generated from qualitative, being presented visually for the authors analysis to deduce core emergent themes and concepts to each interview question. For the 'Compiled Coding Table Data' sets for all questions see Appendix 5.

3.5 ETHICS

'Ethical concerns are greatest where research involves human participants, irrespective of whether the research is conducted person to person' (Saunders, et al., 2016). Therefore, mitigating ethical concerns were consistently undertaken throughout.

1 Ethics Issues Formulating and Clarifying the Research Topic:

Responsibilities towards those who took part in the research topics formulation were recognised, with risk assessments made against choosing potential interviewees to interview. Contacts considered, but who would have created conflicts of interest were mitigated.

2 Ethics Issues During Design and Gaining Access:

Initial consent from all interviewees was outlined upon initial contact with informed consent sought upon interview, ensuring each interviewee gave permission freely based on participation rights and use of the interview data. NDA's were offered*.

3 Ethics Issues Whilst Collecting, Processing and Storing Data:

Firstly, appointed interviewees were pre issued with the interview questions, negating changes and deception issues. Secondly interview audio recordings enabled data analysis accuracy, validity and reliability, with confidentiality agreed. All audio file data was made available to interviewees preventing falsification. Lastly, efforts were made to limit personal bias and/or attempts to lead interviews during each SSI interview to gain objective opinions.

4 Ethics Issues Analysing Data and Reporting Findings:

Objective research was vital, to not misrepresent interview data collected, distort conclusions and inductive theory built. Emphasis on anonymity of interviewees was paramount to protect findings if perceived as adverse outside of the study's academic environment. With research intended to further the subject matters cause within the AECOO industry, care was taken not to adversely affect collective interests of interviewees.

*all interviewees declined.

3.6 LIMITATIONS OF THE STUDY

3.6.1 SECONDARY DATA COLLECTION

- Pace of evolution in the field has gained increased traction, new discoveries constantly change goal posts and direction of conversations.
- Numerous non-published postgraduate academic works were discovered covering AECOO industry and Blockchain but were not considered.
- Overall there were few academic works published on Blockchains use in AECOO industry.

3.6.2 SEMI STRUCTURED INTERVIEWS

- Timeframes within which to research, formulate questions, set up and execute interviews.
- Not all interviewees were Blockchain, BIM or construction experts in their professional field. Answers had potential to be general against questions.
- Author was unable to generate a large enough sample to yield precision of any 'plus or minus percent' variety.
- 2/3 groups of 5-10 individuals in a focus group would be more efficient than 10-20 people interviewed individually.

3.6.4 ADDITIONAL IMPROVEMENT OPPORTUNITIES

- Increase in number of interviewees each stakeholder industry sector interviewed, establishing greater averages of information.
- Inability to conduct second interviews to probe further on the 1st rounds findings.
- Team of researchers to analyse transcripts to limit bias.

4.0

FINDINGS & ANALYSIS

4.1 INTRODUCTION

The following section discusses and analyses the findings from research questions put to all interviewees. This was undertaken with consideration for the inductive approach framework following grounded theory set down in the methodology, using the 2-stage coding process outlined. Both the collation and findings of the research material were then approached with an open a mind, to prevent preconceptions influencing both the data collation, and its representation. In relation to the inductive reasoning the findings were not placed in context of a hypothesis, rather instead to set up the findings to analyse against secondary data researched in the literature review.

Please find the compiled and coded interview data transcripts in Appendix 5. Full transcripts of each individual interview are available on request.

4.2 INDUSTRY

4.2.1 INDUSTRY OVERVIEW

Reviewing the research gathered from all interview participants enabled broad interpretation into the collated data, as well as scope in its understanding. Geographically, interviewees professional interests and focus, while broadly international, was predominantly focused on the 'UK' and 'UAE' markets. With the majority of those interviewed working within globally operating firms, a broad spread of professional operatives was questioned. However, the authors professional contacts led to a greater weighting of interviewees located in both the UK and UAE. While it can be stated an international spread of professionals were interviewed, it unfortunately cannot be seen as truly global in its reach (See Fig 4.1).

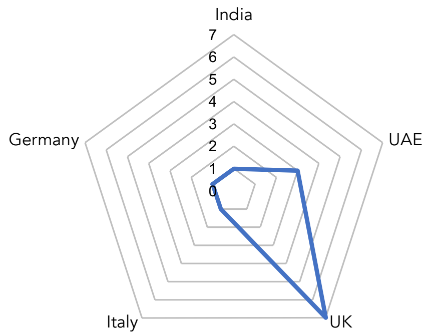


Fig 4.1: Question 1A Results

With interviewees drawn from a variety of professional backgrounds the bulk were from the wider 'Construction Industry' and 'Technology' based specialist fields around predominantly BIM and Blockchain. Significant to the initial methodology design, the key stakeholders relevant to both BIM and Blockchain ecosystems were interviewed. With these diverse backgrounds, this enabled the development of focused insights against the use of both technologies from those who would be required to collaborate in their application (See Fig 4.2).

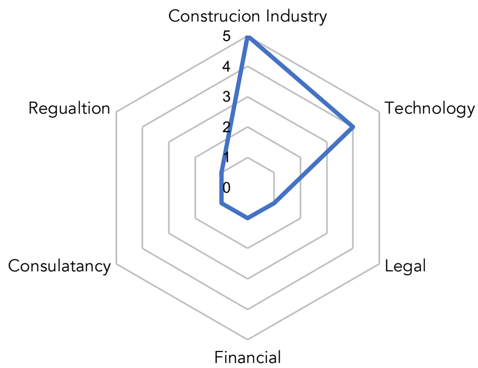


Fig 4.2: Question 1A Results

Focusing on interviewees as stakeholders for the process as laid in in the methodology, the weighting of experience and knowledge towards BIM, Blockchain and the construction industry was essential to understand, both in framing the reliability of those interviewed, but also the breadth of experience necessary to build a representative industry position (See Fig 4.3). With the majority of those interviewed being 'BIM Aware,' 'BIM Expert' and part of the 'Construction' industry it was clear weighting of opinions leant towards those knowledge sectors. It must be emphasized, all those interviewed were aware or involved with Blockchain, while working within the construction, financial, legal, consultancy or purely technology fields.

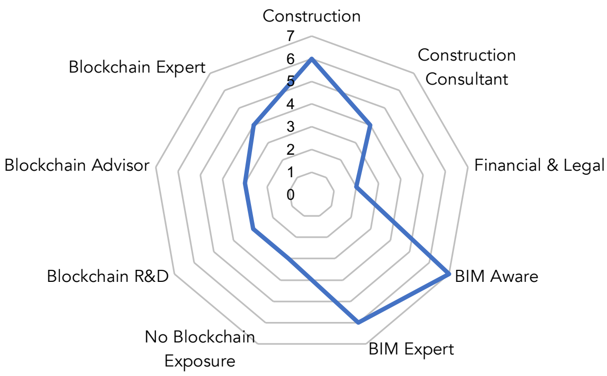


Fig 4.3: Question 1B Results

With uniquely rich observations captured, individual and mutually shared opinions across all stakeholders were revealed. With the key trend concerning technology disruption through 'Data Centralisation,' (See Fig 4.4). Interviewees expressed BIM and Blockchains need for centralisation with the inclusion of both financial and legal interviewees as future key stakehold-

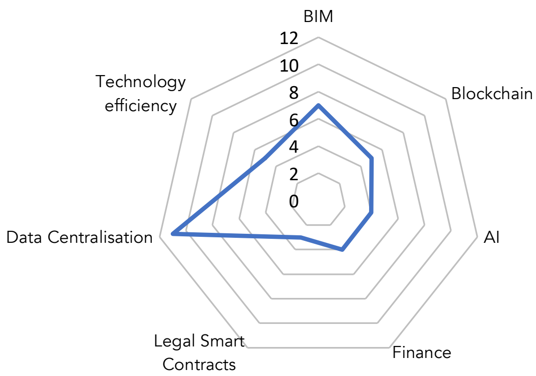


Fig 4.4: Question 2A Results

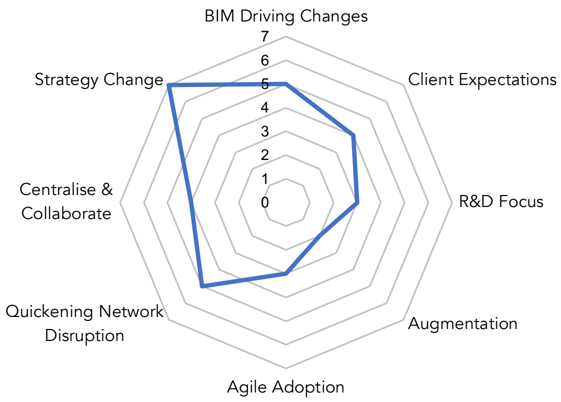


Fig 4.5: *Question 2B Results*

ers stating its importance which was most revealing;

'Centralisation is important. This is probably the key aspect of how us as a legal firm are affected by technology and the new needs our clients are creating for us.' (Interviewee 7, Conducted 16th Sept 2019).

How data centralisation affected interviewees organisations was clarified by 3 clear trends. Findings revealed the critical importance of commercial strategy changes necessitated and inspired by the technology disrupters and overall trend changing markets and industry methods of industry process. The trend was complemented by both disruption within traditional commercial networks and also their new adoption formats centralised data ecosystems. With BIM highlighted again as the key technology driving change, alongside the centralised method BIM collates each consultants design input, the relationship between strategy change, network disruption and BIM driving these was highlighted (See Fig 4.5).

While BIM was indeed clarified as causing industry wide disruption, Blockchains proved more nuanced. Instead being recognised between 3 stages of 'No,' 'Infancy' and clear 'Blockchain Disruption' (See Fig 4.6). Feedback from all interviewees outlined how each of these two technologies influenced their professions related to construction. These ranged from BIM's maturity now the UK government requires its use on public projects, so causing downstream disruption, to blockchains early stage R&D and foundational disruption in finance causing other related stakeholders to take note starting their own research. There was clear conviction of opinion towards both technologies relevance only evolving further within the construction field and while blockchain is only in its infancy, both technologies would only further evolve 'Productivity' benefits moving forward.

'BIM is a cornerstone driving our corporate strategy now to how we provide our services as a multi-discipline professional services construction business' (Interviewee 2, Conducted 18th Sept 2019).

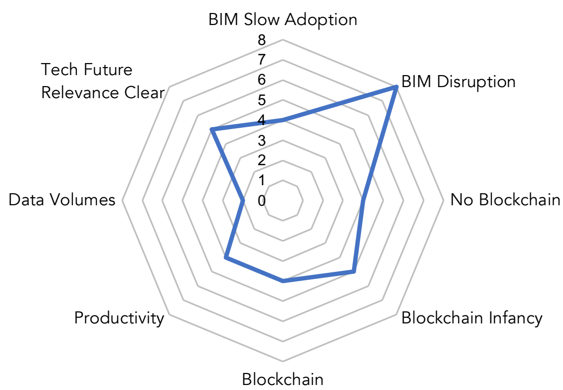


Fig 4.6: *Question 2C Results*

4.3 FEASIBILITY

4.3.1 BIM & BLOCKCHAINS PERCEIVED RELATIONSHIP

Having set the scene, it is crucial to understand the overall feasibility for both technologies working as one. Interviewees highlighted overwhelmingly both BIM and Blockchain should be understood as 'Evolutionary Technologies' (See Fig 4.7). Hype generated around their potential as 'Revolutionary' was deemed purely conceptual with the potential to change industries once mature. However, the process by which they develop to become commercially viable and effect industry was instead deemed evolutionary. ***'Blockchain is a revolutionary concept by what it proposes. However, the reality of any new technology is it must go through an evolutionary process before many of the problems it faces are solved and the wider industry is able to adopt it'*** (Interviewee 12, Conducted 18th July 2019). It is clear from the interviewee's opinions, the inevitable problems faced as evolution occurs will unavoidably contribute to the combined technologies inherently developing 'Slower than Anticipated' with repercussions on the technology's feasibility timescales. ***'BIM, and how slow its developed, has meant adoption has been slowly staggered'*** (Interviewee 5, Conducted 23th September 2019).

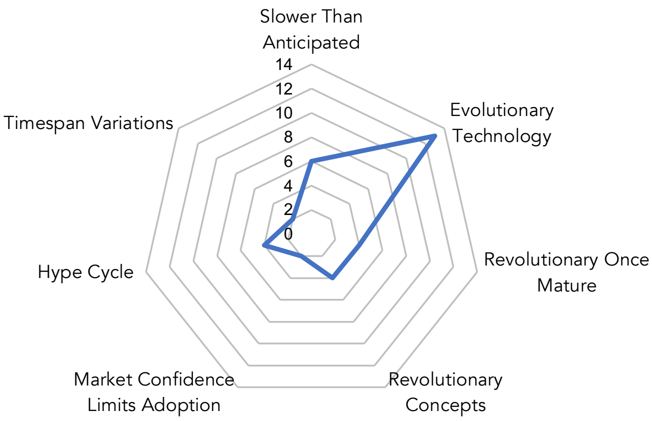


Fig 4.7: Question 3A Results

In understanding the 2 technologies relationships it was important to establish what synergies were perceived, to establish deeper perspectives into the benefits of such technologies following evolutionary development paths. Considering interviewees feedback, findings were analysed against 'Synergies and Anti Synergies' (Ahuja & Novelli, 2017) theory. While BIM and Blockchain offered no one clear horizontal, vertical, strategic or financially clear synergy, weighting from the interviewees revealed 'Horizontal Operating Synergies.' 'Data Transfer Linking' each project's information through the 'Centralisation of Data' spread across the 'Network' of project stakeholders BIM and Blockchain supports, 'Drives Efficiency' benefits and costs by sharing the key asset all stakeholders benefitted from, project data (See Fig 4.8). Such synergies would allow improved co-ordination costs, opportunity resources costs and learning and absorptive capacity costs in knowledge transfer across all parties using BIM & Blockchain. These should certainly be perceived as beneficial for the wider construction industry looking forward.

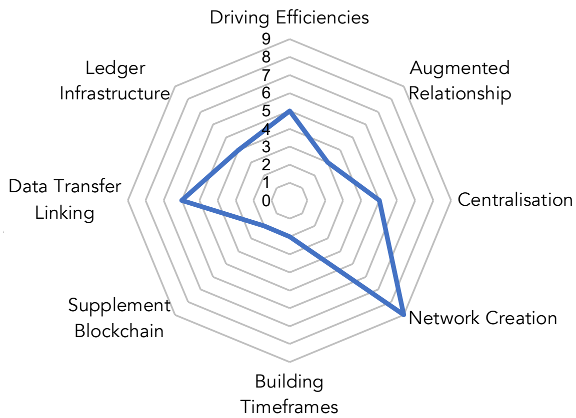


Fig 4.8: Question 3B Results

4.3.2 CURRENT & FUTURE FORESEEABLE CHALLENGES

With BIM established as a viable technology, it would be the intended complementor to Blockchain, which possesses the challenges yet surmounted. Proposed adoption within the industry again requires detailed feasibility analysis. As an overview across a number of questions posed, interviewees perceived 'Human Resistance,' as their key issue to adoption, with the unease of technological change in their respective professional settings being at the forefront of interviewees opinions. ***'It is the fear of change within the industry itself which is perhaps the biggest hurdle'*** (Interviewee 8, Conducted 19th September 2019). However, it was not simply fear of change highlighted, interviewees outlined 'Leadership' and 'Lacking 'Knowledge' as key issues. What can be surmised is a perceived structural weakness to both individual firms and the wider construction stakeholder's ecosystem which is likely to limit adoption (See Fig 4.9).

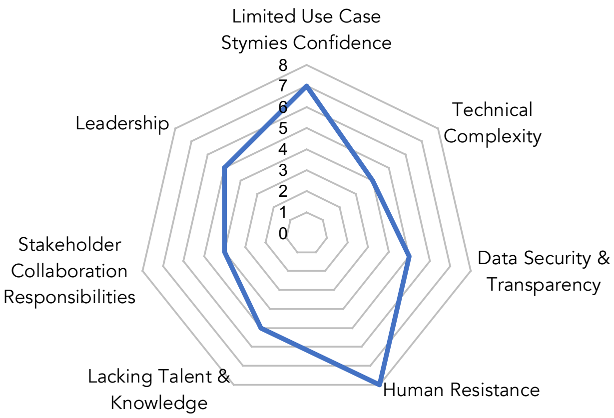


Fig 4.9: Question 4A Results

Yet with Blockchain being so new, and only a handful of AECOO firms initiating R&D on its viability the findings are not surprising. Interviewees expressed 'Limited Use Cases' within the construction industry as a future crucial barrier in building confidence and knowledge about what the technology could offer. With BIM creating its own centralised ecosystem as demonstrated in (See Fig 3.1), there should be consideration for building a project stakeholder ecosystem strategy. ***'You've got to change the dial, the mental dial around these organisations because many of them, indeed 83% of corporates are not prepared as they don't yet understand how to utilise these technologies wider benefits'*** (Interviewee 3, Conducted 1st August 2019).

Considering the innovation inherent in combining BIM & Blockchain, and the establishment in Fig 4.8 of horizontal synergies benefits to those adopters, BIM's established position within the AECOO profession, could be assumed as a blockchain adoption enabler. With interviewee findings again highlighting 'Human Resistance' being a future issue, (See Fig 4.10), it is perhaps the combined concerns of 'Client Expectations' and the 'Multi Stakeholder Commitments' of those working on each project which highlight the perceived inter-relationship challenges within the stakeholder's ecosystem which should be the point of focus. Adoption commitments of the use and technologies relationship BIM and Blockchain proposes, requires all key stakeholders as part of the ecosystem on a project by project basis otherwise benefits in combining both technologies cannot be achieved. Considering the thesis focus concerns both the application of both technologies across the wider construction industry, necessity for a broad industry approach is justified. ***'If the industry's model of delivery using a combined BIM and Blockchain process is both easily understood and easy to execute, across the wider value chain, these issues would be certainly more surmountable.'*** (Interviewee 1, Conducted 17th September 2019).

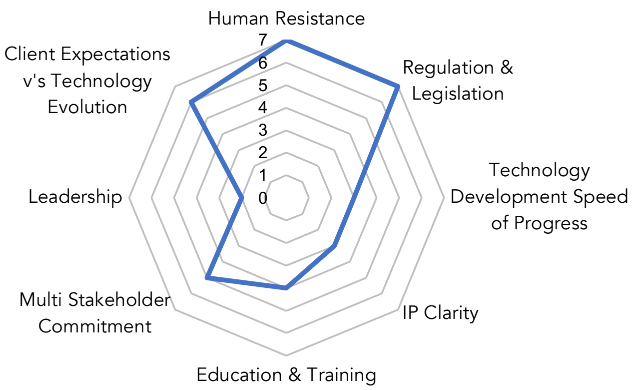


Fig 4.10: Question 4B Results

Consequently, the 'Three risks of innovation' theory must be recognised as a threat to the construction industries ecosystem for BIM & Blockchains adoption and use by all construction stakeholders when recognising the 'Co-innovation Risk', 'Execution Risk' and 'Adoption Chain Risk' against the industry strategy for these technologies use. This is arguably strengthened through interviewees outlining 'Inter Industry Collaboration' being most effective in surmounting the issues BIM & Blockchains combined use would face, (See Fig 4.11). Be that again through the development of 'Industry Use Cases' demonstrating co-operative 'R&D,' ***'Inter-stakeholder collaboration, dialogue and strategic user cases are the only way to bridge these issues'*** (Interviewee 8, Conducted 19th September 2019).

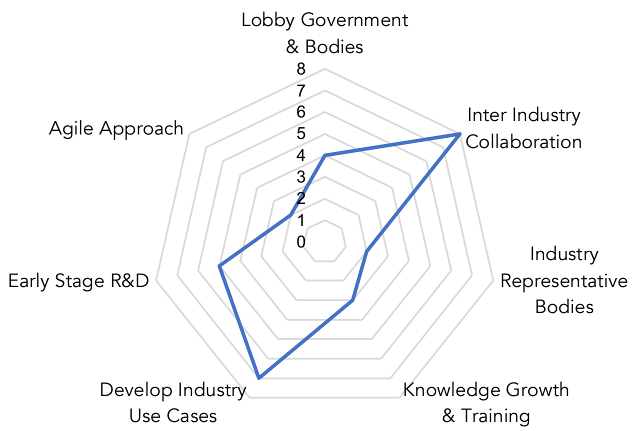


Fig 4.11: Question 4C Results

4.3.3 REGULATORY AUTHORITIES

The majority of those interviewed recognised regulators were crucial as a wider stakeholder to construction projects and as a regulations creator, directly influencing abilities of BIM & Blockchains combined future use within the AECOO industry. How regulation should be implemented, frameworks set, and business environment created in consequence were therefore key interviewees foci, (See Fig 4.13). Findings framed overarching views that while regulation 'Helps' adoption, 'Over Regulation' negatively stifles innovative environments needed to develop new technologies in their early stages. ***'Too much regulation is only going to stifle how the tech is used or how it evolves in ways not yet understood or foreseen. Yet too little and it's the wild west.'*** (Interviewee 1, Conducted 17th September 2019). The historically poor relationship construction has had with new technology led interviewees to recognise the authority's involvement as essential in stimulating and promoting its use in the first place and to provide trust in the technologies use. ***'We're dealing with an industry that's very traditional by nature, so sometimes legislation is required to kickstart the market.'*** (Interviewee 6, Conducted 10th September 2019). With BIM Level 2's mandated use for all UK public projects, the potential strategic legislation would present the AECOO industry was made clear.

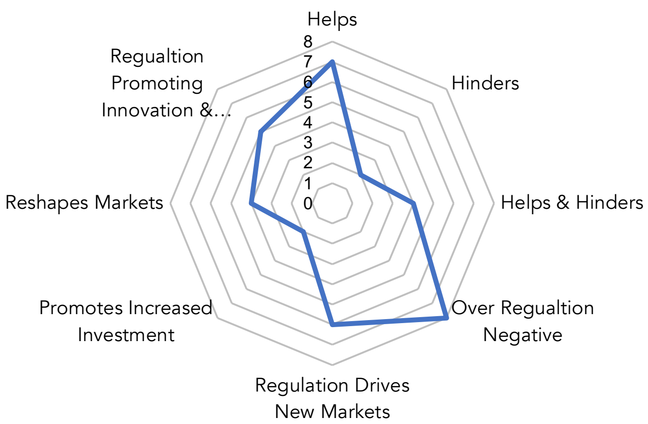


Fig 4.13: Question 5A Results

However, context towards Blockchains current developmental immaturity must be recognised. As such interviewees expressed views more broadly towards 'Regulation Promoting Innovation,' acting as an enabler, not only to business' to invest in Blockchain adoption, but also for entrepreneurs providing solutions to drive blockchain development forward from its developmental stages. ***'Blockchain is in its early days, so really, we would benefit from a softer touch from government, which would enable us to innovate and develop ideas rather than having to satisfy red tape.'*** (Interviewee 12, Conducted 18th July 2019).

Findings against how BIM and Blockchain combined should be regulated further reinforced 'Innovation Promotion' through 'Balanced Regulation' while set with the development of 'Use Case Examples,' in triangulating the interviewees opinions on regulation, (See Fig 4.14). Led by opinions in how regulators are leading stakeholders in early stages of Blockchain such a technology, interviewees posited;

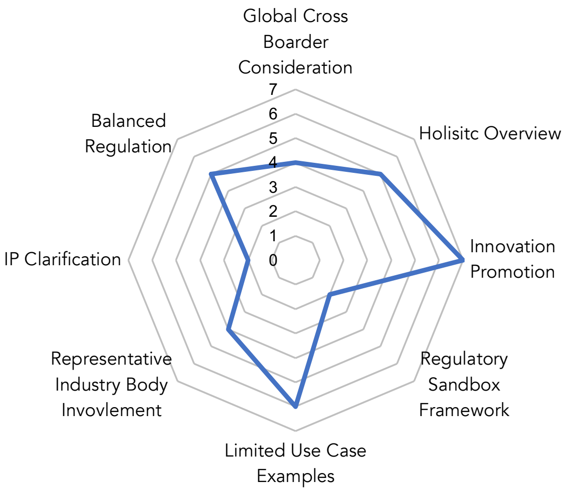
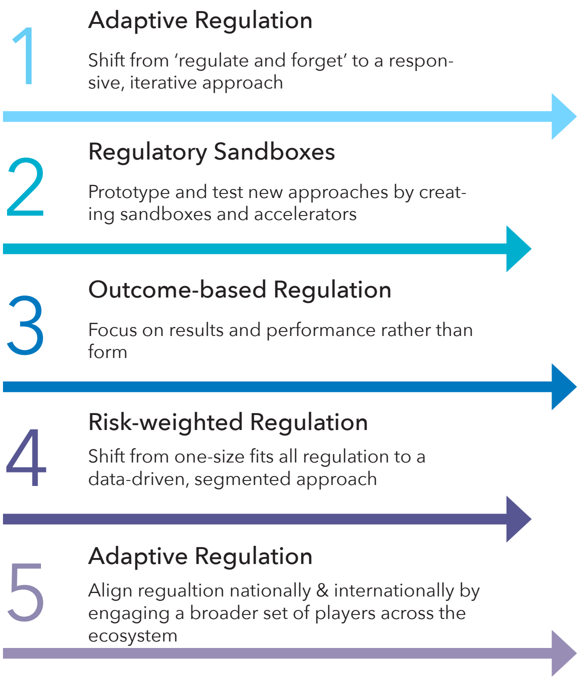


Fig 4.14: Question 5B Results

'If government were to stipulate, they now required BIM and Blockchain to be used in tandem, this would totally revolutionise both the development and adoption of the technology, and while initially only a certain percentage of the industry would be able to conform, it would reshape the market radically.' (Interviewee 12, Conducted 18th July 2019).

With regulators primary interests leading efforts for increased oversight enabling quality assurance, efficiency and clarity of frameworks within which new business opportunities can thrive, it's clear regulator involvement should be perceived as a prerequisite to increased adoption of the combined technologies if the industry considers government as a key stakeholder, not a hinderance. With this in mind, utilising the methodology approach of remaining open to being surprised by findings (See Fig 4.14), highlighted a 'Regulatory Sandbox Framework' suggested by two interviewees, while not a majority finding, was an outside trend of relevance in blockchain regulatory environments. While currently such frameworks are solely used in the Fin-tech industry to promote blockchain use and are a recent creation in order to accommodate blockchain and regulation in unison, its suggested suitability for the construction industry BIM and Blockchain concept was noticeable.



To that effect the suggestion of sandbox frameworks, to promote just this were made a key regulation's focused interviewee;

'The feasibility for a construction focused governmental regulatory sandbox for the construction industry seems obvious. Exploration radical digital innovation within such an environment must be a framework the UK considers, and industry should push for.' (Interviewee 13 Conducted 28th Oct 2019).

Fig 4.12: *The Future of Regulation: Principles for Regulating Emerging Technologies (Eggers, et al., 2018)*

4.4.1 CURRENT & FUTURE INDUSTRY OPPORTUNITIES

With productivity benefits BIM and Blockchains use could enable, findings and analysis of interviewee's opinions and opportunities such a relationship could create, was central to understanding the value creation both technologies could generate. Accordingly, interviewees stated at macro levels such a technology combination would indeed lead to new 'Long-Term Value Creation' as the core essential driver by which productivity issues would be addressed, (See Fig 4.17).

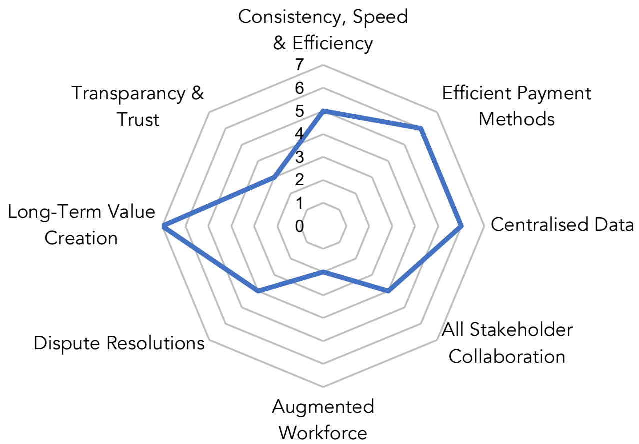


Fig 4.17: Question 6A Results

Understanding how value could be created is central to the development in how blockchains potential could be harnessed, since value is the singular metric which adds positive contribution to all other standard outcomes in each construction project. The basic premise recognised by interviewees centred around identifying cohabitational potentials BIM and Blockchain's unison proposes. ***'BIM would seem to be Blockchains natural partner with both technologies complementing each other's weaknesses'*** (Interviewee 8, Conducted 19th September 2019). Interviewees outlined traditional value creations blockchain use would likely create centred around the security through its distributed leger structure creates, with both the positive intended and unintended consequences born from this. Highlighted in interview, these aspects ranged from 'Efficient Payment Methods,' mitigating established construction industry weakness, to increased 'Dispute Resolutions' through ledger records of project data. ***'Its ability to increase traceability, transparency, auditability and early dispute resolution, so dispute avoidance really throughout the whole design and construction process which at present causes huge wastage'*** (Interviewee 10, Conducted 19th September 2019).

However, set against the more immediate benefits ledger recorded design data could bring, specific interviewees outlined value creation centred around 'Centralised Data' BIM creates and Blockchain would record transactions of. In essence the creation of a self-contained centralised ecosystem fed by data inputted. Such an ecosystem would be a 'multilateral set of partners interacting for a focal value proposition to materialise' (Adner, 2017). In such a scenario ***'centralising design data and having the ability to register the information on that data would give an enormous power both to those who create it and potentially to those who inherit it in future'*** (Interviewee 12, Conducted 18th July 2019).

With the growing majority of the AECOO industry designing projects in BIM, interviewees recognised immutable value in BIM's data beyond the physical construction stage. Each project would create a merged physical and digital representation. ***'Over the longer term the value proposition becomes how valuable is the BIM data over the life of the built asset?'*** (Interviewee 5, Conducted 23th September 2019). As clarified by the interviewee majority, BIM's 'Digital Asset Lifetime Data Value,' (See Fig 4.18), if taken in context, would be the creation of

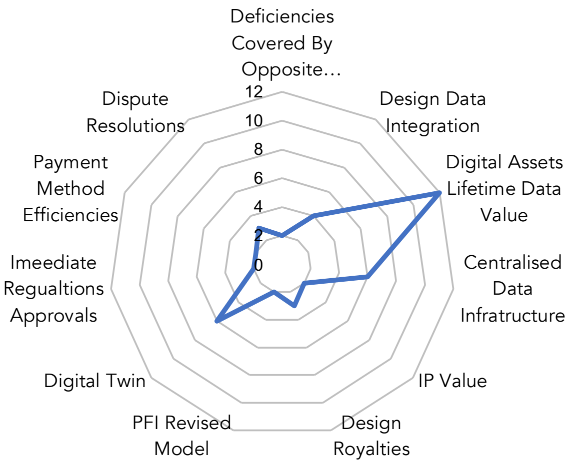


Fig 4.18: Question 6B Results

centralised digital representations of each construction project, through BIM, creating what interviewees recognised as the 'Digital Twin' of a physical built asset. When underwritten by Blockchain however, this ***'would enable the use of the BIM model data beyond the buildings point of construction, extending the data's life through the full life cycle of the building itself'*** (Interviewee 5, Conducted 23th September 2019).

Indeed, a combined technology enabled ecosystem accentuates wider value creation. With all stakeholders contributing to each BIM model, interviewees noted the model acted as a digital deposit, growing its value with each new data input over time, such that ***'consultants who have worked on a project contributing to the centralised model could be rewarded over the lifetime of a buildings existence rather than just being paid for the contract of the work they do at that point in time to say, design a building'*** (Interviewee 3, Conducted 1st August 2019). In essence interviewees highlighted the creation and monetisation of BIM represented and Blockchain recorded 'IP Value' for the key stakeholder's project design contributions through the prospective BIM & Blockchain digital assets lifecycle. However, difficulties in creating and implementing such a proposition are obvious. Would only new buildings be capable of leveraging the data and value the two technologies suggest? How would both industry and authorities transition perhaps across to such a new value generating proposition? 'You would have to run a hybrid system for arguably a certain period of time' (Interviewee 6, Conducted 10th September 2019). Even so would this cover all projects and legislative oversight, or perhaps ***'we end up in a blockchain environment that is a project to project or sector to sector in its use, or are we going to end up with a globally used blockchain format?'*** (Interviewee 5, Conducted 23th September 2019).

	DEFENSE	OFFENSE
KEY OBJECTIVES	Ensure data security, privacy, integrity, quality, regulatory compliance and goverance	Ensure data security, privacy, integrity, quality, regulatory compliance and goverance
CORE ACTIVITIES	Optimise data extraction, standardization, storage, and access	Optimise data analytics, modeling, visualization, transformation, and enrichment
DATA MANAGEMENT ORIENTATION	Control	Flexibility
ENABLING ARCHITECTURE	SSOT (Single source of truth)	MVOT's (Multiple versions of the truth)

Fig 4.15: *Elements of Data Strategy (DalleMule & Davenport, 2017)*

Taken as a whole the findings represented in both fig 4.15 & 4.16 represent such variety of opinion it is clear that the data itself is the value creation opportunity. Utilising the BIM SSOT necessitates data support both generated and analysed though an effective data strategy. ***'Construction companies using BIM and whatever the next evolution is needed to build clear digital strategies to manage all this data they are creating, which I've yet to see. Security is one aspect of it, but the retained value within the data they hold is another. If not, then I'd say they won't transition to the next interconnected generation companies will become.'*** (Interviewee 9, Conducted 20th September 2019). With construction operating in a highly regulated environment, set against the 'Data Strategy Spectrum' (DalleMule & Davenport, 2017) (See Fig 4.16), a defensive strategy built around BIM'S SSOT so pursuing data security and regulatory compliance is essential, however certain offensive data characteristic would be advisable to enable value creation form the data gen-

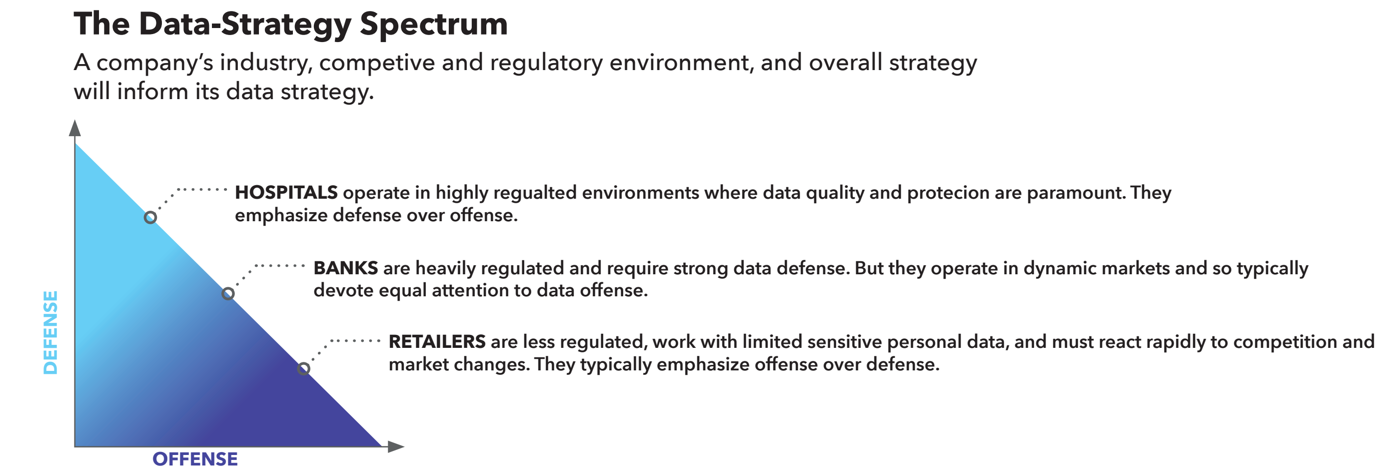


Fig 4.16: *Data Strategy Spectrum (DalleMule & Davenport, 2017)*

erated on BIM. Therefore, consideration must be made to company structures who have yet to build a data strategy and strong data management framework (See Fig 4.15), particularly with distributed technology solutions and blockchain coming into play. (DalleMule & Davenport, 2017)

4.4.2 INDUSTRY FRAGMENTATION & PRODUCTIVITY

Analysing how the fragmented nature of the wider AECOO industry both effects productivity and consequently the value enabled by BIM and Blockchain revealed interviewees diverse positions. Weighted majority of opinion fall towards industry 'Low Margins' creating price sensitivity for AECOO project stakeholders, with the cost competitive process outlined as a consistent test for the financial wellbeing of both industry and individual project stakeholders (See Fig 4.19). How such an environment stimulates technology investment and adoption however was questioned from both sides in the findings. On one side interviewees outlined 'Lower Financial Ability' for companies to respond positively to new technology use. ***'Low margins in this industry simply do not help companies invest in strategic foresight and innovation'*** (Interviewee 10, Conducted 19th September 2019). Viewed through 'Five Forces' analysis it is the 'High' bargaining power of the clients towards lead stakeholders and on to construction subcontractors via competitive tender processes facilitating low margins (See Appendix 2).

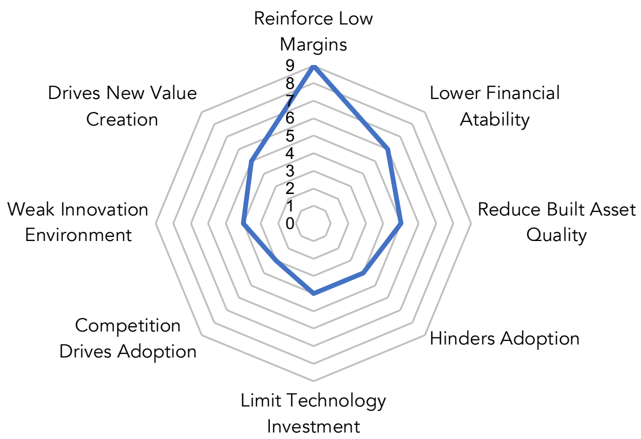


Fig 4.19: Question 7 Results

Yet contrasting this, interviewees saw necessity for a competitive environment to enact a survival of the fittest with individual stakeholders ambition a necessity for the prosperity of their position. ***'Competitiveness should and will drive technology adoption. Organisations must be seeking new ways of securing a competitive advantage and cutting-edge technologies give them that opportunity if they are to survive and thrive'*** (Interviewee 2, Conducted 18th Sept 2019). On reflection both sides of the interviewee's positions are equally valid, they are in fact the opposite sides of the same coin with problems posed and the actions required to in consequence. Indeed, interviewees highlighted the conundrum ambitious consultants keen to push forward face in adversarial environment price sensitive markets create.

'The catch 22 situation is consultants need higher returns to be able to invest, but extreme cost competitive approaches to construction projects mean the further away from the centre you are, the less viable stakeholders ability to invest in programs such as BIM or Blockchain will become' (Interviewee 7, Conducted 16th Sept 2019).

Again, viewed through the 'Five Forces' analysis, this set of process between stakeholders clearly frames the competitive rivalry within the construction industry as being 'High,' (See Appendix 2).

With all construction stakeholders presently competing through technology, innovation and its integration to optimise their costs and productivity, such high rivalry in fact creates unstable foundations Arguably enabling 'Weak Innovation Environments' with "Limited Technology Investment' interviewees highlighted, due to the fragmented industry and protectionist culture presently. 'The reality with the current construction industry model boils down to over competition with diminishing returns within industry. Such a competitive environment severely weakens each company's ability to plan longer term or adapt to shocks in their job pipeline or wider industry' (Interviewee 9, Conducted 20th September 2019). In such a weak environment as presented by those interviewed, ***'the fragmented nature of the construction industry is perhaps the fundamental problem why core technologies within the industry don't easily become ubiquitous'*** (Interviewee 7, Conducted 16th Sept 2019). Alongside, longer-term costs and loss of productivity due to extreme competitive processes was outlined by interviewees as 'Reinforcing Low Margins.' Consequently, adverse effects on projects undertaken was stated with interviewees clarifying, the 'High' bargaining power of clients, and 'High' competitive rivalry within the industry increased risks in achieving what each stakeholder agreed to. In the Carillion case, this led to the companies demise, however for many lesser scenarios as outlined by key interviewees instead ***'a crippling effect of the competitiveness in the market is that it is either the cheapest or the best-known consultant who's awarded the contract, and therefore almost never the best. This often has adverse effects on the outcome of the built asset and for those consultants responsible'*** (Interviewee 10, Conducted 19th September 2019). Perhaps this issue in itself calls into question the self-defeating consequences of an overtly cost competitive process 'Hindering Adoption' of technologies with productivity consequently remained historically weak.

4.5 ECONOMIC VIABILITY

4.5.1 COMMERCIALISING NEW TECHNOLOGIES

Focus on how BIM & Blockchain combined justify their economic viability is essential to ascertain where its optimal use cases lie. With interviewees establishing 'Industry Data Collaboration' between all project partners as central for the technologies commercial viability, (See Fig 4.20), recognition of the necessary collaborative framework BIM and Blockchain both require was acknowledged. As an established central plank necessary for its operation and viability, interviewees outlined how this effected management thinking on influencing adoption.

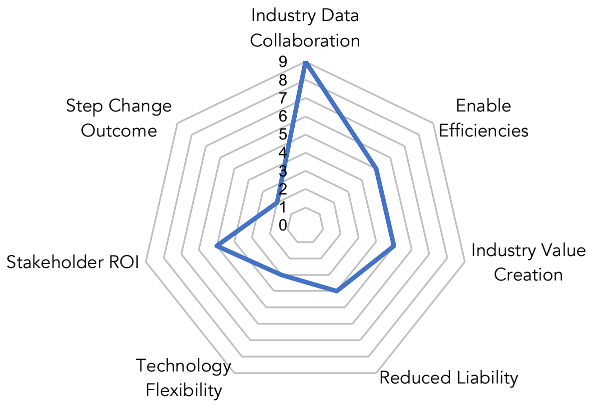


Fig 4.20: Question 8A Results

'Our strategy is we are looking at technology adoption based on a centre of gravity approach where we want to rationalise and streamline which technologies we choose and the effective returns we gain' (Interviewee 5, Conducted 23th September 2019).

The simple test outlined to clarify these gains transpired as ***'technology must provide solutions which favourably outweigh the previous method in which to complete the same task'*** (Interviewee 8, Conducted 19th September 2019). Yet this is perhaps too simplistic, instead, to what degree must the new solution outweigh the old, or how must its disruption offer such significant benefits over the present? With interviewees outlining 'Stakeholder ROI' as essential in their perception of adoption, the degree to which BIM now radically innovative a step change BIM and Blockchain would be for industry is essential.

'No company will be willing to pay for technology that doesn't offer a long-term ROI' (Interviewee 10, Conducted 19th September 2019).

With the theoretical work of Schumpeter (1934) highlighting 'creative destruction' as essential in transforming markets, specific interviewee findings indeed confirmed this position where ***'creativity and disruption are needed in order to transform the issues of the industry which can't be fully understood and solved unless they are explored broadly,'*** (Interviewee 1, Conducted 17th September 2019). Yet Nerkar and Shane (2007) outlined, excessively radical innovation risks taking too long to come to market, being rendered redundant by shifting sands in the industry and prospective marketplace. With interviewees recognising new 'Industry Value Creation' as crucial to BIM and Blockchain's feasibility, the degree to which this generated radical 'Step Change Outcomes' in fact was of least importance in the findings. With key technology specialist interviewees recognising this challenge ***'excessively disruptive concepts while helping to reshape the narrative around the issues they want to solve, I see often getting lost in the developmental stages, so no telling in what form they might finally emerge, whether they will even serve the same problem initially conceived for or if anyone wants what their selling,'*** (Interviewee 9, Conducted 20th September 2019).

With the established industry transition to networks and platforms, the necessity to enable economic viability for BIM & Blockchains integration hinges on core stakeholders willing participation. With the author having established both technologies require all project consultants to be recipients and contributors on the BIM network, findings confirmed 'Industry Data Collaboration' amongst all stakeholders as essential to enable the two technologies ecosystem to flourish effectively. However outside of the core stakeholders, again it was the authorities as the external stakeholder who was highlighted as central for any technology to have strong commercial grounds moving forward. ***'It is the government's position which matters most'*** (Interviewee 1, Conducted 17th September 2019).

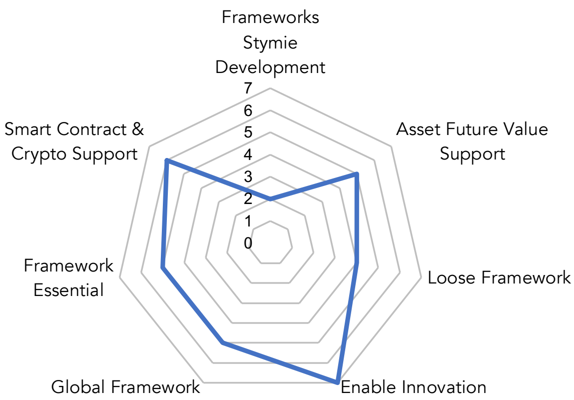


Fig 4.21: Question 8B Results

Consequently, the legal framework surrounding BIM and Blockchains integration born by the government authorities was clarified as ***'absolutely critical for the long-term commercial viability of any new technology'*** (Interviewee 8, Conducted 19th September 2019). Interestingly interviewees saw 'Smart Contracts and Crypto Support' as essential to the perceived ecosystem BIM and Blockchain would likely create, (See Fig 4.21). Both were discussed as essential pillars for the two technologies combination, underpinning rational for blockchains ability in enabling long term value creation alongside abilities to recompense each data creator along the lifespan of the built assets digital twin, and deemed the 'Asset Future Value Support.' None the less while consensus agreed such frameworks must 'Enable Innovation' at a minimum, concern was raised for the ongoing immaturity blockchain expressed with legal and technical interviewees outlining ongoing current concerns. ***'The legal side of smart contracts are tricky and a minefield at present because of the immaturity of the technology and walls around its use,'*** (Interviewee 11, Conducted 8th August 2019). With the international commercial context most interviewees work within, the concept of a 'Global Framework' around how the technologies standards should be resolved to both enhance its technological viability but also satisfy each international governmental stakeholder was highlighted. With BIM and Blockchain being a cloud-based technology, how such oversight could occur is not yet apparent and poses viability risks. ***'Legal frameworks only apply to the jurisdictions they're built for and accepted in. Blockchain, like the internet, almost knows no borders. A legal framework here is likely to have a counterpart somewhere on this planet where the opposite is valid. How this issue evolves remains open'*** (Interviewee 10, Conducted 19th September 2019).

With literary review research outlining limited collaboration through protective behaviour between stakeholders, undermines innovation and in turn the economic viability of any new technology, interviewees responses outlined 'Enabling Innovation' alongside 'Industry Data Collaboration,' in context of BIM and Blockchain, collaboration is indeed central to the ability to commercialise these two technologies.

'Collaboration between all key industry stakeholders and the sharing of data and knowledge arguably is the technologies biggest asset. If this is curtailed or stakeholders silo themselves off, then its game over in my view' (Interviewee 9, Conducted 20th September 2019).

4.5.2 NEED FOR TRUST & CROSS INDUSTRY SUPPORT

How should both industry and individual firms develop what is by nature, a cross party collaborative technology? Outlined previously, collaboration between AECOO stakeholders was deemed necessary to enable commercial viability, yet interviewees overwhelmingly deemed 'Consortiums Ineffective,' (See Fig 4.22). Consensus outlined concern for the structure and effectiveness of their outcome, highlighting ***'consortiums end up becoming a talking shop with too many competing views and vested interests in what the technology should offer and how it should be implemented'*** (Interviewee 1, Conducted 17th September 2019). Concern rests on issues of technology ownership over what could prove to be a radical evolution in how BIM is used, and value created for the industry. ***'Concern around the consortia model is who is taking the revenues? Who owns the IP?*** (Interviewee 11, Conducted, 8th August 2019). Counter arguments outline the more construction stakeholder representatives around the table to discuss their needs then the more positive a solution. ***'Consortiums are an effective method to brainstorm the industry problems and develop a solution which benefits all'*** (Interviewee 12, Conducted, 18th July 2019). Overall 'Independent Development' was deemed to be the method of pursuit with market forces governing viability of each BIM and Blockchain technological offering. However, key interviewees outlined consortium approaches being best suited working with the broader industry, building collaborative consensus between stakeholders on Blockchain horizontal technology platform infrastructures. The vertical technology offerings be those Blockchain IOT are best developed independently. ***'BIM & Blockchain would provide the infrastructure upon which other hang their ideas. If the infrastructure is ineffective then nothing will actually hang of long'*** (Interviewee 12, Conducted 18th July 2019).

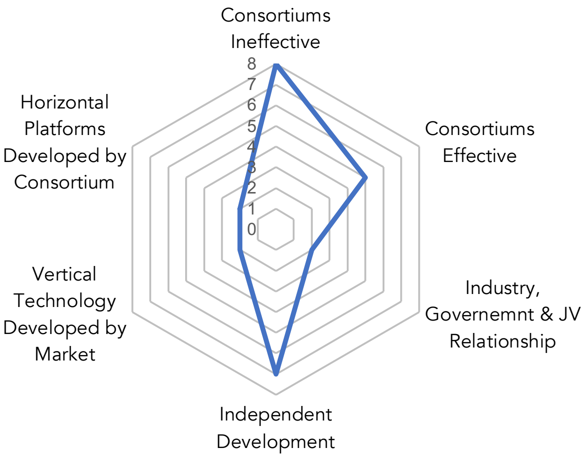


Fig 4.22: Question 9A Results

Yet findings revealed, lack of trust stifles collaboration within the industry, intern directly undermining the economic viability for the technology. Blockchain by its very nature is a trust enabler through collaboration ***'trust is critical as we see blockchain as a mechanism through which technology meets trust'*** (Interviewee 8, Conducted 19th September 2019), (See Fig 4.23). With the fragmented nature of the AECOO industry leading to lack of trust between stakeholders, interviewees outlined this as a positive driver towards adoption of transparent Blockchain technologies. ***'Blockchain however is built on the premise of trust through transparency, so really once you have accepted the use of the technology, then trust is only reinforced by the technology's execution'*** (Interviewee 12, Conducted 18th July 2019).

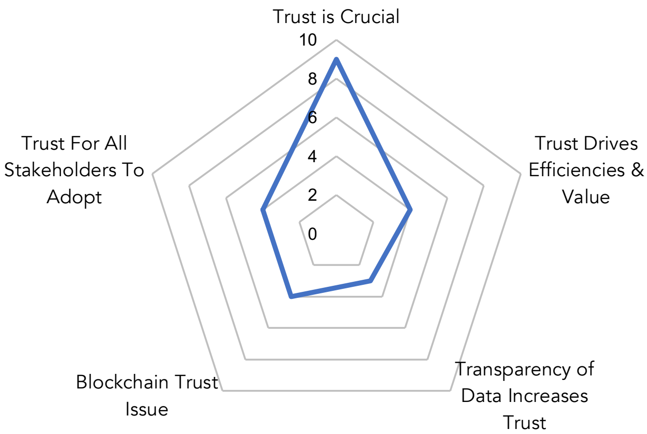


Fig 4.23: Question 9B Results

Opinions focused towards collaborative value creation were indeed more nuanced, yet it is clear again trends between construction stakeholders tend towards the 'Centralised Data'

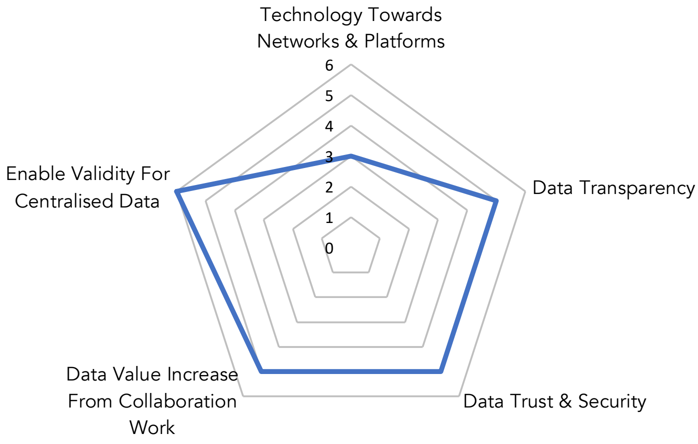


Fig 4.24: Question 9C Results

model BIM creates and Blockchain would underpin, (See Fig 4.24). Such judgements on centralisation were reinforced as crucial in supporting both the ability in 'Data Trust and Security' for single source of truth (SSOT) data infrastructure the BIM model is built on and the inherent 'Data Transparency' this requires to build, collaboration enabling a 'Data Value Increase' on the SSOT itself. '***Technology can facilitate trust and transparency but ultimately it depends on the quality of the inputted information entered'*** (Interviewee 8, Conducted 19th September 2019).

With both corporate, public and governmental voices raising increased scrutiny over how technologies creating and storing centralised data are managed, the importance of 'Data Trust and Security,' interviewees argued would only accelerate. ***'Everyone nowadays is concerned about their data, so trust is absolutely essential if we are going to be putting all of our work into a digital format in one location'*** (Interviewee 1, Conducted 17th September 2019). Blockchains offering to BIM was therefore outlined as data validation and ledger infrastructure necessary reinforcing collaborative value for AECOO into the future. ***'Any technology, particularly Blockchain which can better reinforce the ability to collaborate together with an increasing level of trust is only going to be positive to what that technology offers value wise'*** (Interviewee 1, Conducted 17th September 2019).

4.6.1 TIMEFRAMES FOR THE TECHNOLOGY & INDUSTRY

While relevant findings and analysis over the feasibility, value and economic viability for BIM and Blockchain have been depicted, it is also crucial to understand timing frameworks around which to place these before recommendations can be made. Within the literature review it was established technology suffered slow adoption within AECOO, therefore when revolutionary new technologies stake claims of their potential in changing such conditions analysis of 'Gartner's Hype Cycle' is relevant.

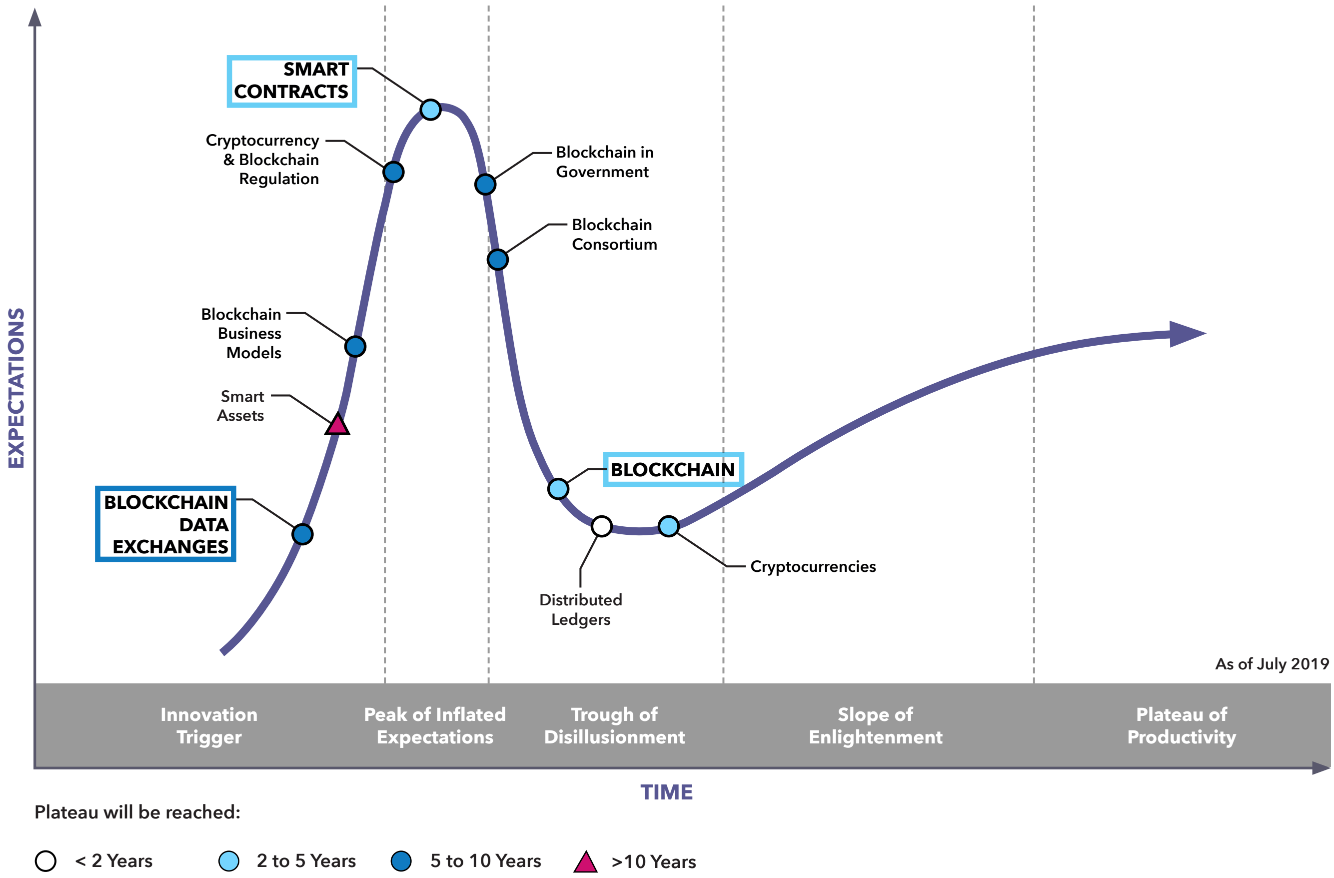


Fig 4.25: *Gartner Hype Cycle: Blockchain July - September (Gartner, 2019)*

Blockchains currently development position alongside the specific technology BIM requires from Blockchain, the 'Blockchain Data Exchange (BDE),' recording data transfer between each stakeholder is represented in Fig 4.25. It can be established while Blockchain technology more generally is in the 'Trough of Disillusionment' while BDE is in early stage 'Innovation Trigger' phase. Currently there are no clear use cases of BIM and Blockchain within the construction industry to position this specific combined technology on the cycle. Interviewees established the predominantly held opinion BIM and Blockchain would indeed face the 'Hype Cycle Reality' as all new technologies run through their lifecycle stages, as such it was clear blockchain 'Technology Will Suffer Similarly' in its uptake within the AECOO industry.
'It will more than likely suffer this issue – full stop. There are significant numbers of hurdles

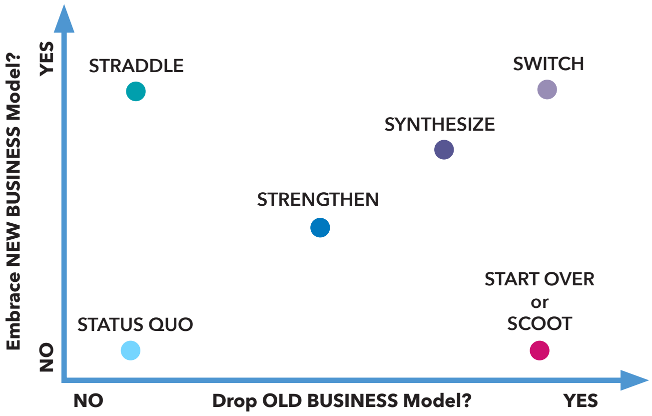


Fig 4.26: *Business Model Response to Disruption (Ahuja & Novelli, 2016)*

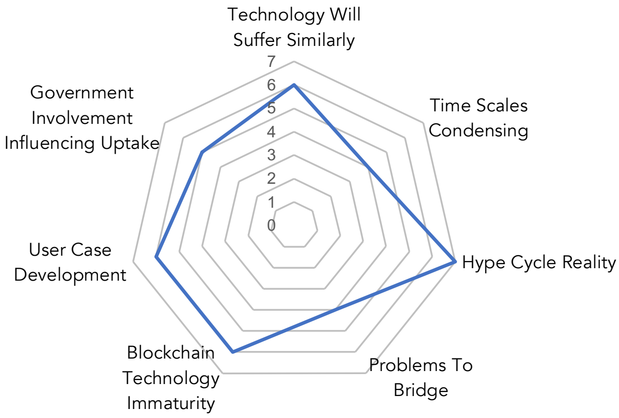


Fig 4.27: Question 10A Results

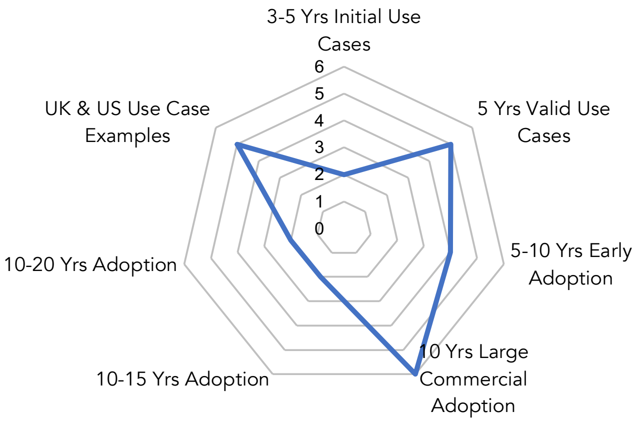


Fig 4.28: Question 10B Results

the combined technology has to get over, some unique and geographically or project specific, or against many other contexts. So yes, it is more than likely to be adopted at a slower pace than we yet realise' (Interviewee 10, Conducted 19th Sept 2019).

Those interviewee stakeholders working with blockchain directly highlighted 'Blockchains Technology Immaturity' across both legal, financial and construction fields at present. Interviewees outlined two potential ways by which adoption could be better influenced. Firstly, in line with the current 'Hype Cycle' findings interviewees outlined the need for 'User Case Development' in establishing the usability of Blockchain with BIM demonstrating its viability.

Secondly 'Government Involvement Influencing Uptake' though mandating its use or enabling government commercial partnerships in exploring the viability for public project and sector use through 'Sandbox' partnerships. Reviewing how the Hype Cycles current timeframes for both blockchain and BDE sit in July 2019, against interviewees responses, two clear overlapping time brackets were highlighted. With Gartner's BDE having a 5 to 10 year expected period until clear adoption in the 'slope of enlightenment' phase, Blockchain technology itself is foreseen as 2 to 5 years off a similar position. Interviewees similarly stated 10 years before initial large practice adoption of the technologies with 5 to 10 for early adoption and 5 years for valid use cases, (See Fig 4.26). As such interviewees data corroborates that of Gartner's estimates timeframe.

Strategically timeframes effects on commercial approaches for implementing the combined technology would depend on industry appetite and each companies market position. However, with interviewees outlining the necessity for new 'Use Case' examples as essential to be developed alongside current methods ***'It would be very much a parallel technology system that will be tested against the more traditional methods taken as the most appropriate course before traction is gained'*** (Interviewee 6, Conducted 10th Sept 2019). Consequently, responding to such disruption to support such a dual approach requires a supporting business model.

Through the necessity to retain the current traditional model in support of AECOO's current BIM Level 2 operations, while simultaneously adopting a BIM and Blockchain supporting model, each stakeholder could implement a 'Straddling Approach' (Ahuja & Novelli, 2016) over the shorter-term windows adoption use cases are predicted (See Fig 4.27). It would not be suitable until the later timeframes as outlined from 10 years onwards for the dual approach to be supplanted by a 'Switch' approach, conforming back to a singular business model built solely around BIM and Blockchain.

5.0

CONCLUSIONS

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With Industry 4.0 now upon us, the construction industry faces an inflection point. Set against the influence of the growing digital economy, this research piece underscores the increasing rise of BIM and its yet unrealised potential. With both the industry and government finally recognising its true potential (McMorrow , et al., 2019), these findings highlight the growth of centralised data platforms and the necessity for complementary DLT systems. The opportunity for positive transformational innovation to benefit the industry is clear.

This research has shown Blockchain as a centralised leger concept is, at present, immature in both its development and commercial acceptability. However, its pace of evolution is disrupting the financial and legal industries even though hype surrounding its potentially revolutionary applications has relevant digital security concerns both industry and government stakeholders must yet address. Such technology is therefore evolutionary, with technical setbacks, stakeholder sceptics and market problems yet to be overcome. With blockchains opportunity within the construction industry not as a standalone technology but a complementor, acting as the ledger infrastructure to all BIM's data flows and project consultants decisions, the industries opportunity to transform oversight and value it creates, both for its clients and project professionals all along the value chain would seem transformational.

Now with the introduction of connected technologies through IOT's, the construction sector has the prospect to adopt a futureproofed infrastructure enabling as yet unrealised data-streams further building onto the BIM model. Such a proposition, growing the data value of digital asset paired against the physical built asset and underpinned by a centralised Blockchain ledger posits transformational opportunities. The potential over how the industries stakeholders manage their digital footprints and leverage data and fine new value could reverberate at both an individual and industry wide level.

With the conceivable redistribution in how reward is granted for the value creation within a BIM model ecosystem, blockchains proposition argues to radically alter the way by which value contribution is measured within the construction industry from lead consultants to subcontracts.

Although viable in principle all core stakeholders from government through to legal, financial and professional construction bodies, must be part of the narrative for the frameworks to evolve around such radical technological innovations. It is clear these regulatory frameworks and government endorsement are critical in both enabling and steering technological opportunities. In the face of the increasing pace of radical disruption, it is essential key stakeholders come to the table to forward plan, so the tracks are laid in securing the future transcendence of BIM + Blockchain, so realising Level 3 potential and the positive amelioration for industry productivity.

5.2 RECOMMENDATIONS

5.2.1 RECOMMENDATION 1

'A Legislative Frameworks through Government and Stakeholder Collaboration'

The necessity to build a clear and supportive government legislative framework underpinning the business case for BIM and Blockchains radical new technology proposition, as of yet not present for the AECOO is paramount. Due to the overt collaborative complexity the technologies proposal necessitates with blockchains adoption, the underscored need for use cases in both testing and demonstrating the technologies inter industry ability is essential. With both consortia and open market markets assessments proving inconclusive due to industry fragmentation it is recommended a digital AECOO industry regulatory sandbox framework be pursued. Underpinned by government, the collaborative environment would enable live testing of the proposed Blockchain solutions in both vertical and horizontal strands of the BIM platform's ecosystem against light regulatory supervision. Enabling AECOO stakeholder participants to innovate faster at lower costs within the construction sectors highly regulated environment, while safeguarding sufficient consumer protection it would underpin the building of a groundswell in confidence towards the technologies tentative early stages feasibility, thereby progressing adoption at faster pace than historically predicated. With the core advantage of sandbox environments being that they allow regulators and innovators to work constructively together, when the alternative is currently a fragmented industry, extreme competition and hostility which in turn stifles innovation and innovative environments. With the nature of international boundaries construction data flows across, it is imperative a collaborative regulation approach is advanced in aligning regulation internationally through engaging broader sets of industry and legislative players across the wider AECOO, BIM and Blockchain ecosystem.

5.2.2 RECOMMENDATION 2

'A Framework for Data Strategy'

In acknowledging the increasing gravitational pull of data centralization through BIM, it is essential the AECOO industry's individual stakeholders develop data strategy and management frameworks as a fundamental support alongside the distributed technology solution of BIM and Blockchain. Necessity for each AECOO project stakeholder to manage data security while monopolising value from streams of new data BIM Level 3's collaborative ecosystem validates the need for a clear strategy. This in turn supports the achievement of fabled productivity gains theorized for the industry through the use of both combined technologies. Hence, it is recommended with the construction industries highly regulated environment, necessity for collaboration and longer-term timeframes of construction projects, a defensive strategy driven by data quality and protection are paramount over the use of data to react rapidly to competitors and market changes. This is evidenced by BIM's centralized SSOT enabling architecture. Even the pursuit of a defensive position is rarely static such that value must be attained by each stakeholder through offensive intentions in the data use the BIM and Blockchain secured project model contains as it is evolved through its digital lifecycle alongside the built asset.

5.2.3 RECOMMENDATION 3

'A Strategic Business Model Approach to BIM and Blockchains Innovation Adoption'

Supporting the adoption of BIM and Blockchains combined technologies will prescribe evolutions necessary for the business model required in supporting of its use. However, it is the timeframes of the technology's evolution from its initial use and current early stage development forward which will dictate the appropriate approach.

Consequently, in order to balance a transition and in the highly regulated environment of the construction sector, it is recommended, industrywide to adopt a dual strategy 'straddle' approach both retaining the current traditional process the AECOO industry functions, while simultaneously evolving the adoption of a secondary model. With stakeholders required beyond just the AECOO sector in order to support the proposed dual technologies viability; namely legal and financial. It is envisioned to run the model's side by side as the technology and wider industries ecosystems weighting build up to the point of inflection around the technologies broad ability for adoption.

Conducted in two separate teams running traditional BIM Level 2, and the evolving Level 3 in parallel, through the 'straddle' business model approach, this position will enable the time periods the industry suffers from in both developing and adopting such radical innovation, to be accommodated. With industry both prepared once BIM and Blockchains technological maturity transpires in the wider ecosystems enables BIM Level 3 throughout the wider AECOO industry, businesses in the longer term would be advised to then to 'Switch.'

5.3 FURTHER RESEARCH

Through the development of this research piece, it is clear the use of blockchain though a DLT framework in advancing the sector towards BIM Level 3 and the opportunities for the wider AECOO industry are at present only understood to a limited degree. Necessity for research into the effects of education and knowledge transfer between academic and technological fields and how this can both support and accelerate the wider ecosystem adoption for the combined technologies of BIM and Blockchain is necessary.

Currently there is no information present around government sandbox regulatory environments for technology testbed developments with the construction sector, either theoretical or in use. Presently this new approach is solely focused on the Fintech industries, however, should be seen as equally applicable to the construction sector and its digital technology opportunities. Research into how this could be formatted, what industry needs from government in order pressure the set-up of such frameworks and how the intended outcomes would inform wider regulation and industry support would be necessary.

6.0

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